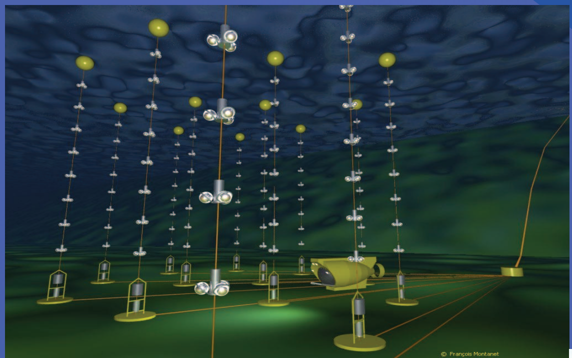
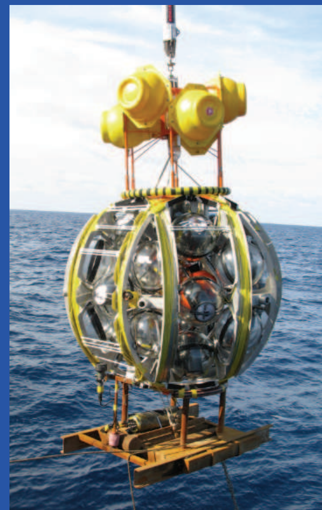
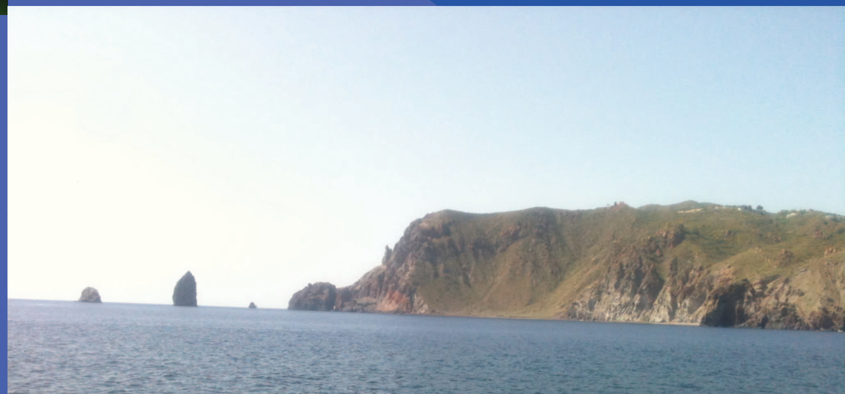
High-Energy Neutrino Astronomy
with the
ANTARES deep-Sea Cherenkov detector
and with the future
KM3NeT Telescope
in the
Mediterranean Sea







Antonio Capone,
University "La Sapienza" and I.N.F.N. Roma, Italy
on behalf of ANTARES and KM3NeT

Dipartimento di Fisica
Sapienza Università di Roma
Istituto Nazionale di Fisica Nucleare

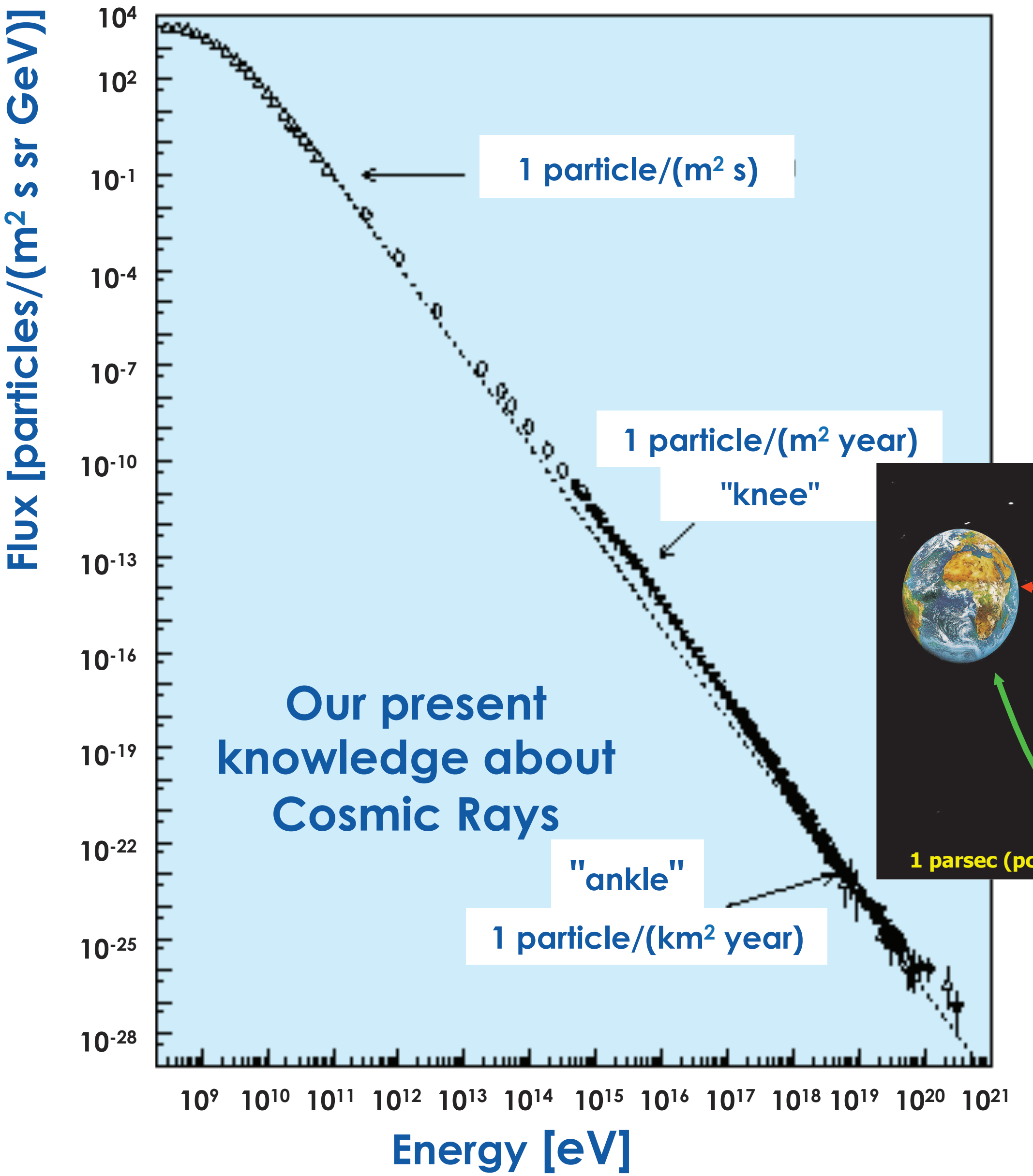
Outline

- **Physics motivation for a Mediterranean Cherenkov Neutrino Telescope**

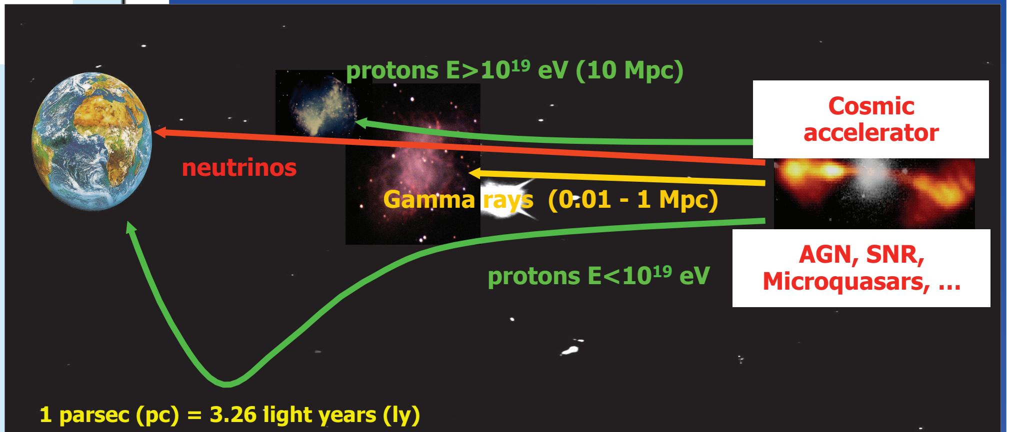
- **The ANTARES Cherenkov Neutrino Detector:**
  - detector properties, angular and energy resolutions
  - selected recent data analysis and results

- **Aiming at Km^3 Neutrino Telescope in Mediterranean Sea:**
  - ANTARES + NEMO + NESTOR + … : joined efforts, design and technologies defined in a common project: KM3NeT
  - Pan-European coordination of funding agencies and research Institutions
- **Active synergies with marine-sciences deep sea researches**
- **Status and perspectives**

The Universe is transparent for UHE neutrinos !



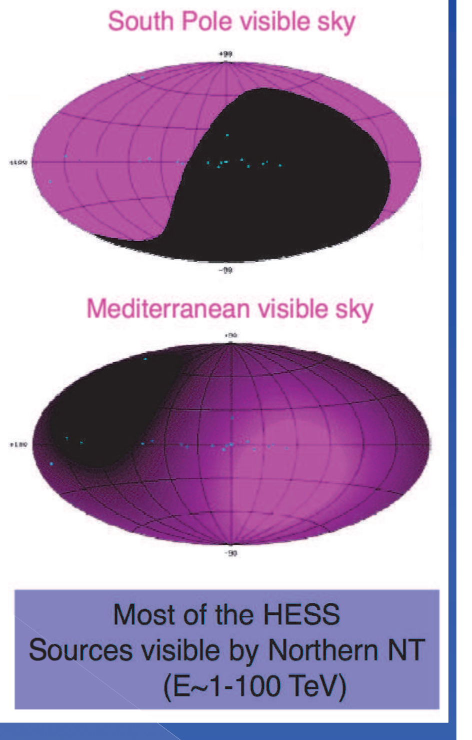
- Observed elementary particles or nuclei carrying a kinetic energy up to 10^{21}eV (like a tennis ball moving at ~150km/h)
- Many open questions:
  - Where they come from ?
  - Which acceleration mechanism ?
  - …



- **UHE astrophysical neutrinos will extend the limits of the "visible" Universe.**
- **Multi-messenger observations**

Physics with a Mediterranean Neutrino Telescope

- No doubt **HE ν's** are **very important messengers** (hadronic HECR origin ?, parent's acceleration mechanisms, wider horizon, unexplored territory,…).
- **Technical feasibility** of HE ν telescopes is **proven** (under ice, under water).
- **Complementarity** to the South Pole **IceCube** detector
- **HE ν's signal observed by IceCube** (many events in a region where the visibility is exceedingly good for Med Telescopes).



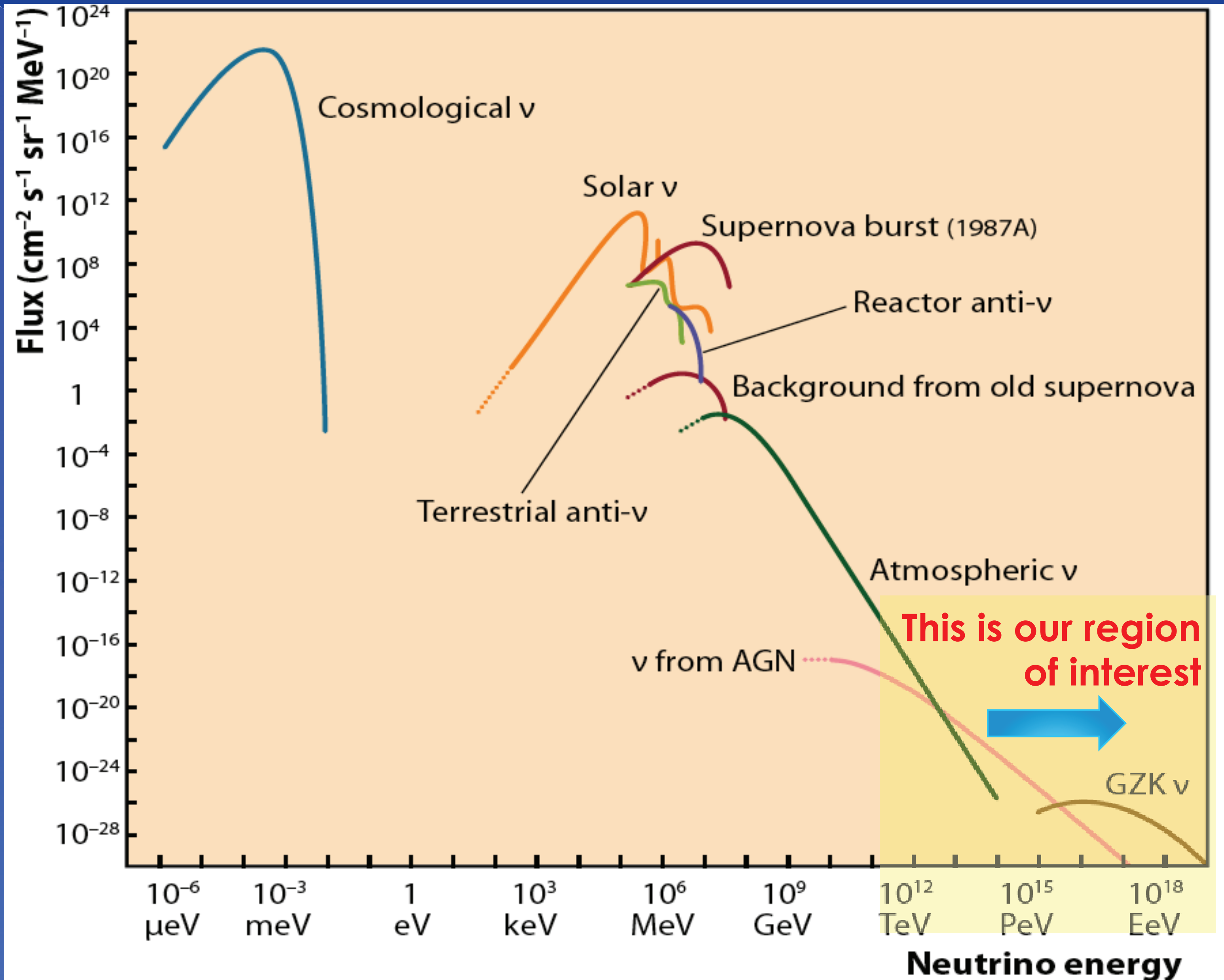
Central scientific goals:

- galactic neutrino sources ($1 < E_\nu < 100$ TeV, point-like)
- high-energy diffuse neutrino flux
- extragalactic sources
- Dark Matter (indirect detection)
- Neutrino properties
- Exotics (monopoles, nuclearites, sterile neutrinos...)

… and in a multi-messenger approach:

- origin of cosmic rays, internal dynamics of sources and acceleration processes

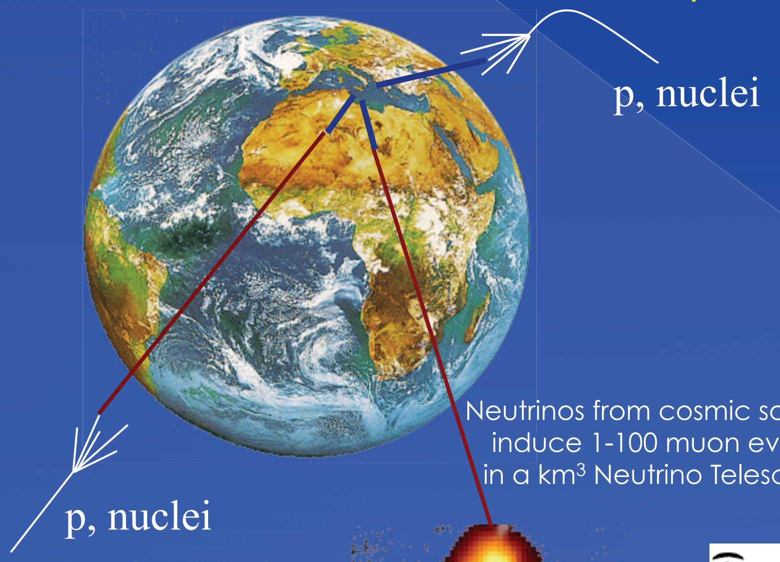
Neutrino fluxes: what do we know/expect ?



Detection principle

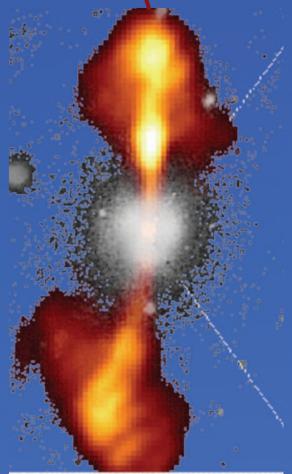
Search for neutrino induced events, mainly $\nu_\mu N \rightarrow \mu X$, deep underwater

Down-going μ from atm. showers
S/N ~ 10^{-6} at 3500m w.e. depth



Neutrinos from cosmic sources induce 1-100 muon evts/y in a km³ Neutrino Telescope

Up-going μ from neutrinos generated in atm. showers
S/N ~ 10^{-4}

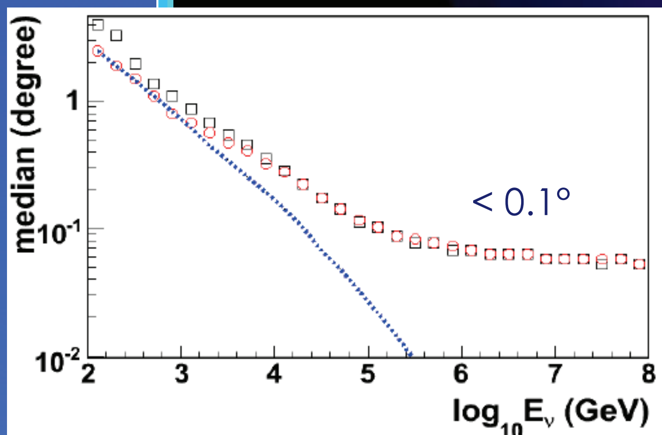


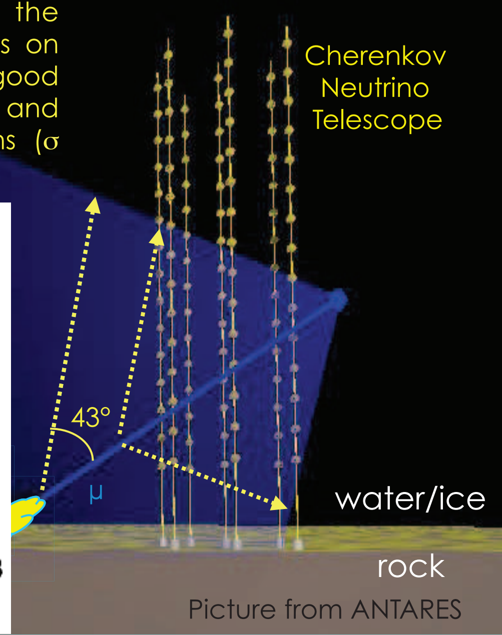
- Atmospheric neutrino flux ~ E_ν^{-3}
- Neutrino flux from cosmic sources ~ E_ν^{-2}
  - Search for neutrinos with E_ν>1÷10 TeV

- ~TeV muons propagate in water for several km before being stopped
  - go deep to reduce down-going atmospheric μ backg.
  - long μ tracks allow good angular reconstruction

$$For\ E_\nu \geq 1TeV \quad \theta_{\mu\nu} \sim \frac{0.7°}{\sqrt{E_\nu[TeV]}}$$

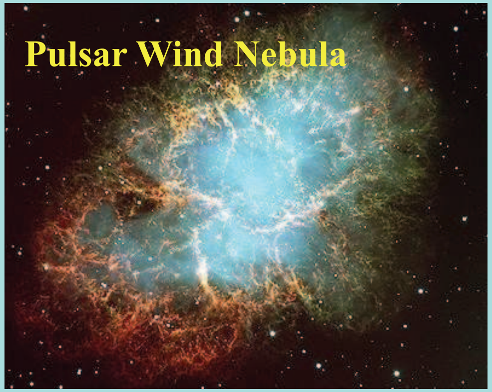
μ direction reconstructed from the arrival time of Cherenkov photons on the Optical Modules: needed good measurement of PMT hits, σ(t)~1ns, and good knowledge of PMT positions (σ ~10cm)

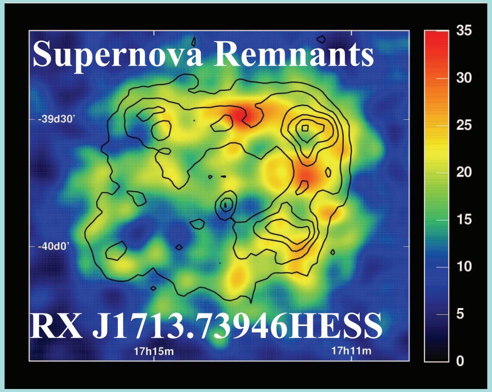


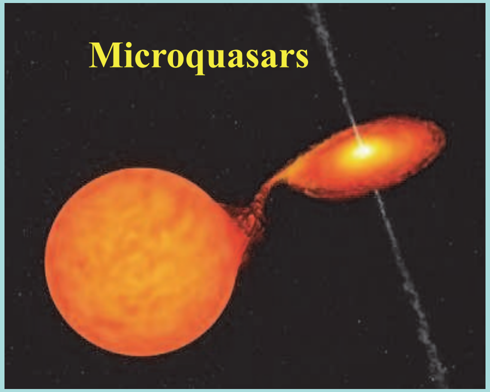


Search for "Point like" cosmic Neutrino Sources

Galactic



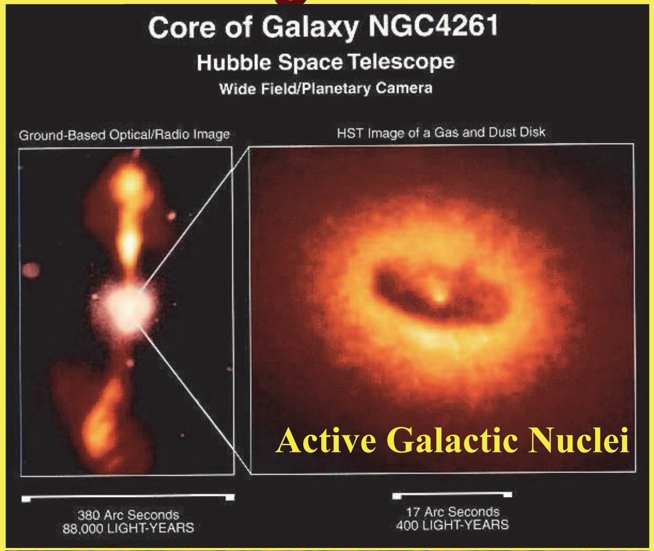


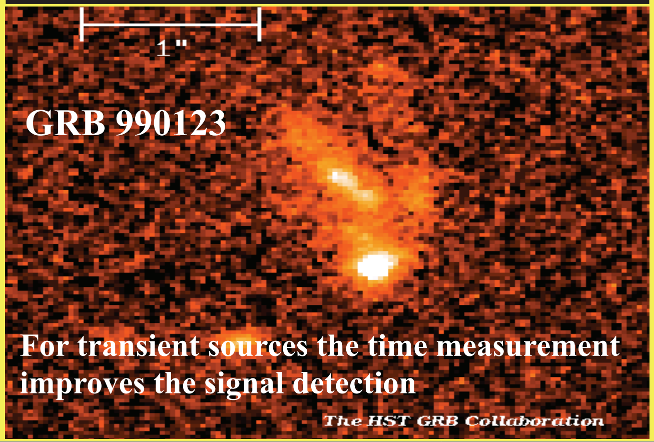


Their identification requires a detector with accurate angular reconstruction

$$\sigma(\vartheta) \leq 0.5^\circ \text{ for } E_\nu \geq 1 TeV$$

Extragalactic



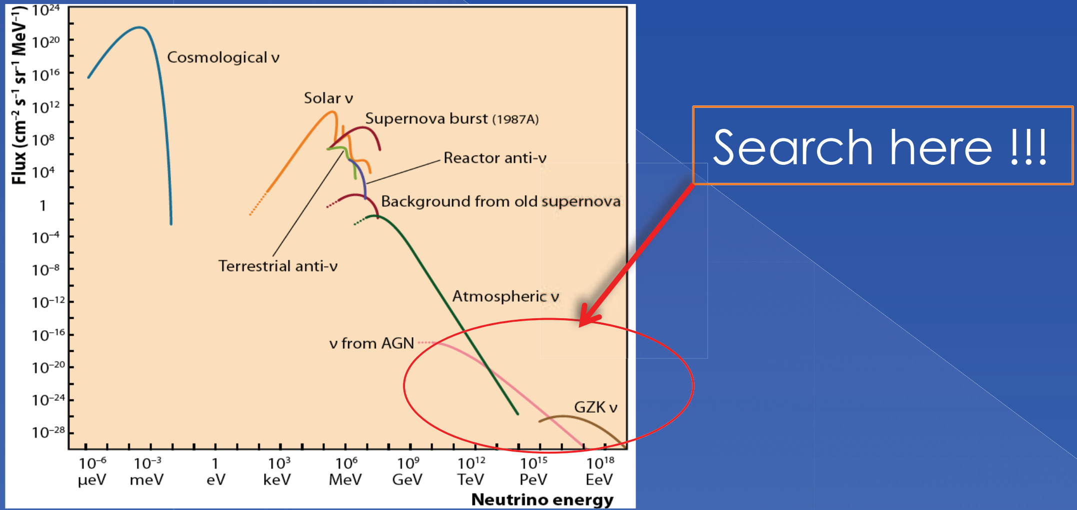


Experimental signal : statistical evidence of an excess of events coming from the same direction

Search for ν from "Diffuse Cosmic Neutrino Sources"

- Unresolved AGN
- Neutrinos from "Z-bursts"
- Neutrinos from "GZK like" p-CMB interactions
- Neutrinos foreseen by Top-Down models
- ....

Their identification out of the more intense background of atmospheric neutrinos (and muons) is possible at high energies (E > TeV) and implies accurate energy reconstruction.



- 2013, first evidence for a diffuse flux of cosmic neutrinos: 28 contained VHE astrophysical ν events reported by IceCube

The ANTARES Collaboration

8 Countries

- France
- Germany
- Italy
- Morocco
- Netherlands
- Romania
- Russia
- Spain

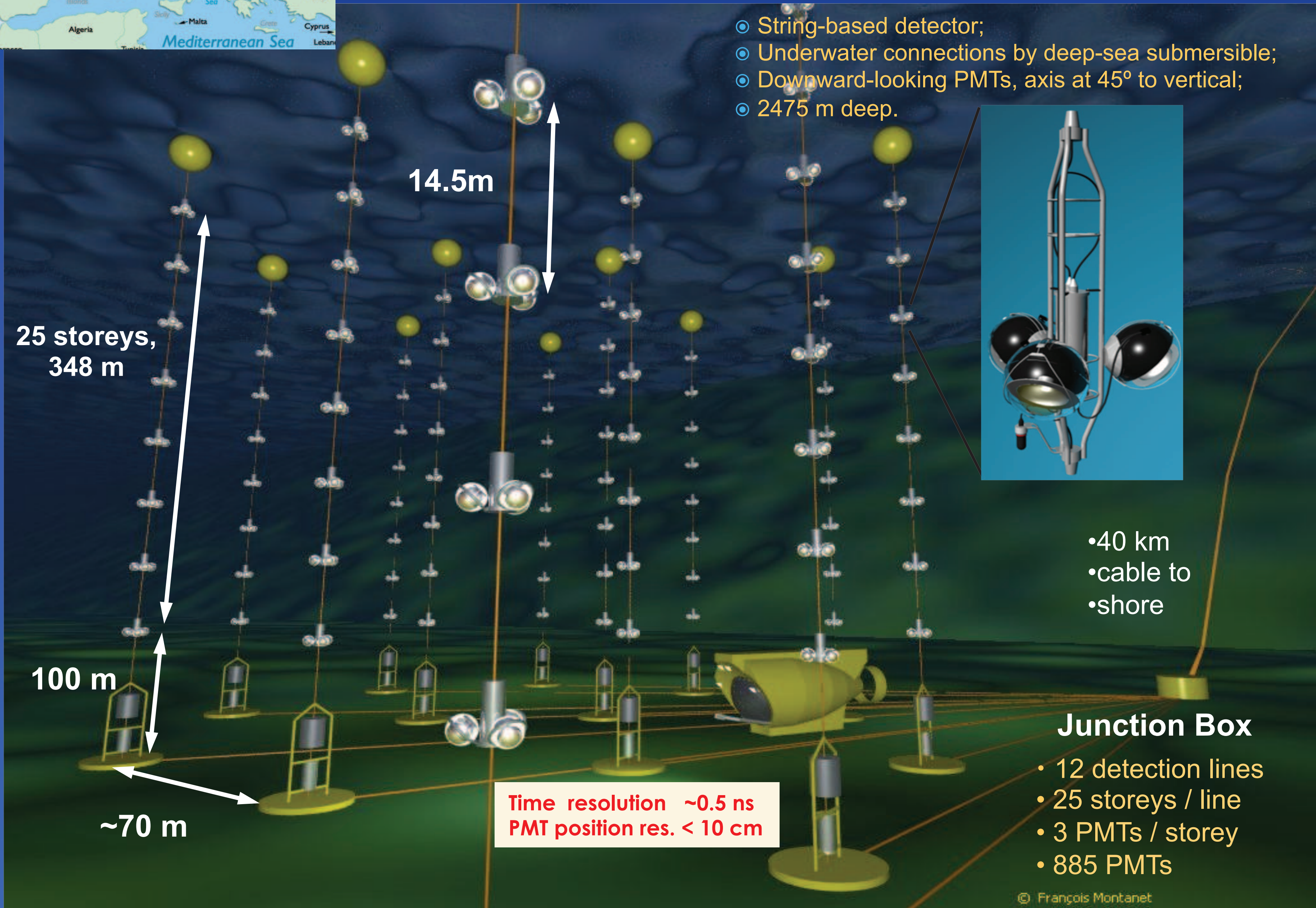
31 Institutes

≈ 150 scientists

The ANTARES detector

NIM-A 656 (2011) 11-38

- String-based detector;
- Underwater connections by deep-sea submersible;
- Downward-looking PMTs, axis at 45º to vertical;
- 2475 m deep.



Time resolution ~0.5 ns
PMT position res. < 10 cm

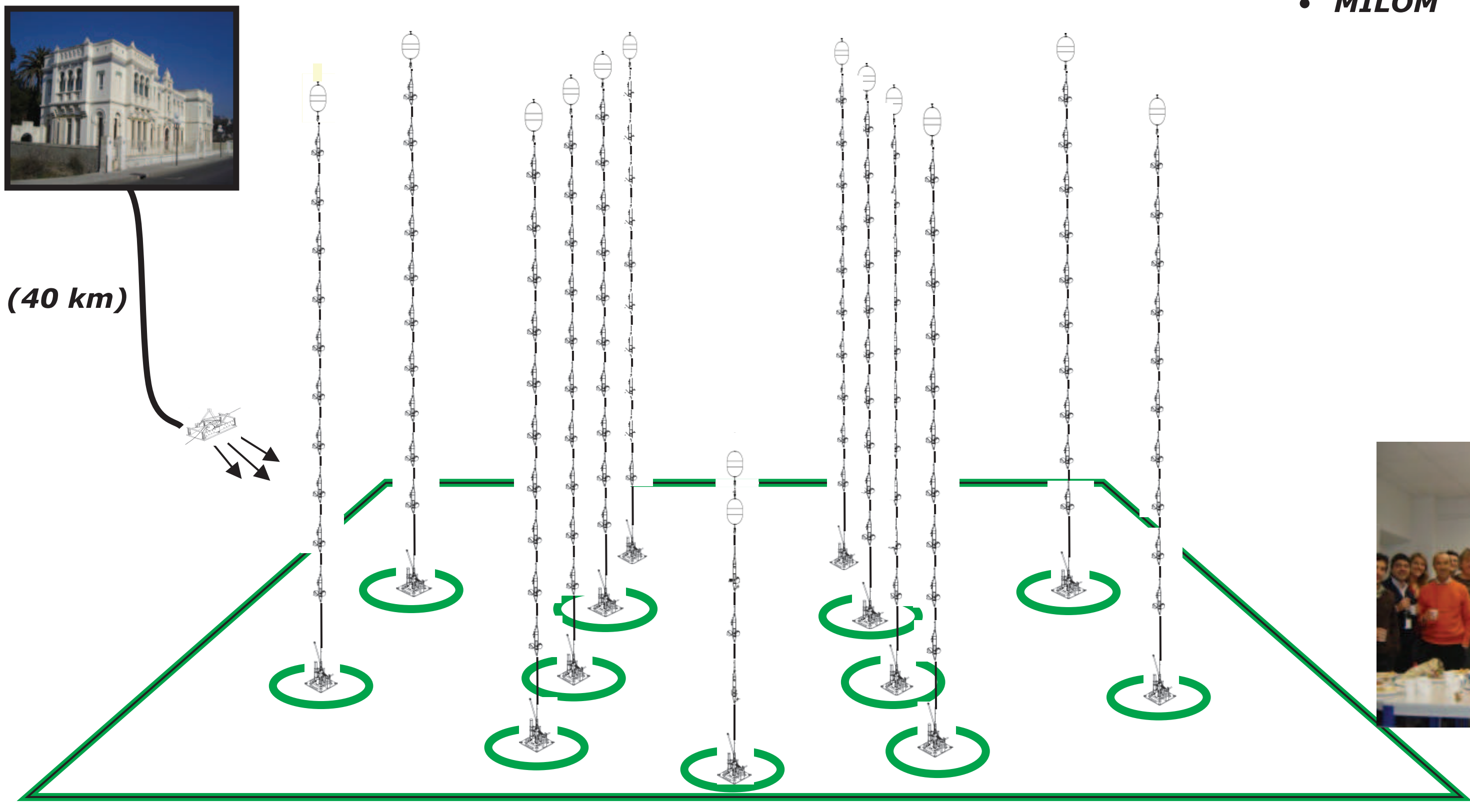
- 12 detection lines
- 25 storeys / line
- 3 PMTs / storey
- 885 PMTs

Deployment

Data taking periods:

- ***MILOM : Mar '05 – Mar '06***

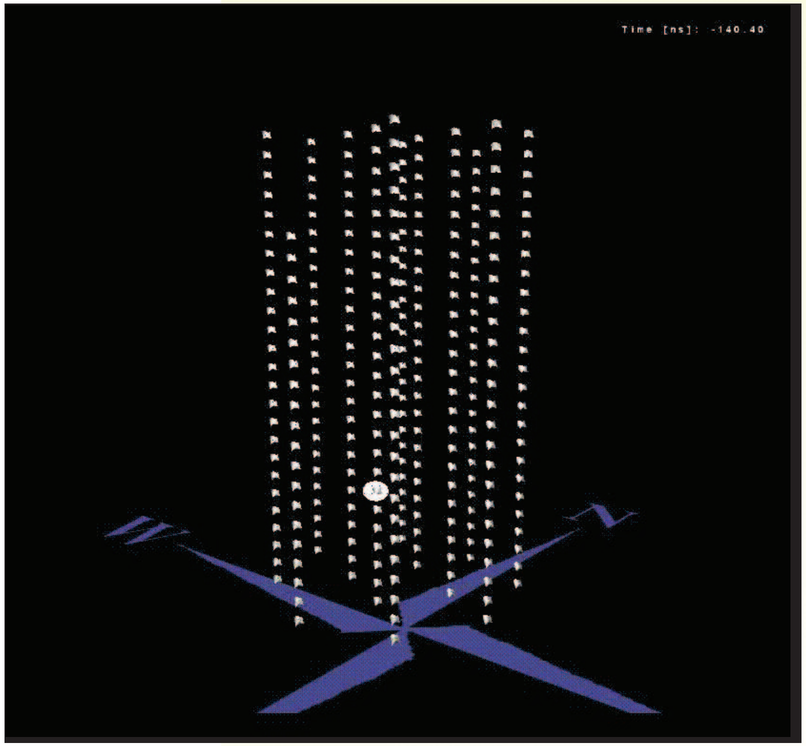
La Seyne-sur-Mer



(2.5 km depth)

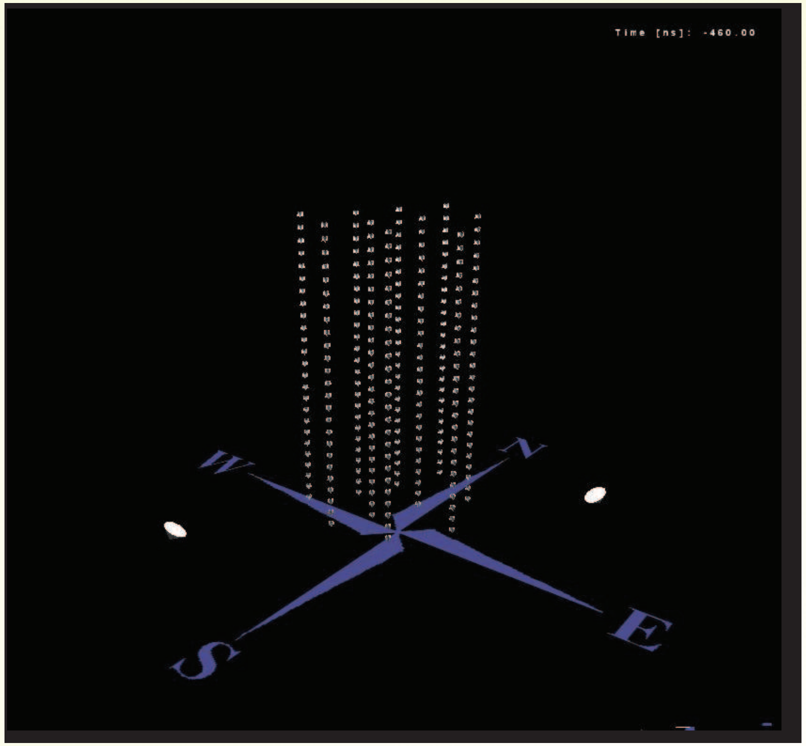
(multi-) muon Event

Example of a reconstructed down-going muon, detected in all 12 detector lines:



Up-going track: a neutrino candidate

Example of a reconstructed up-going muon (i.e. a neutrino candidate) detected in 6/12 detector lines:



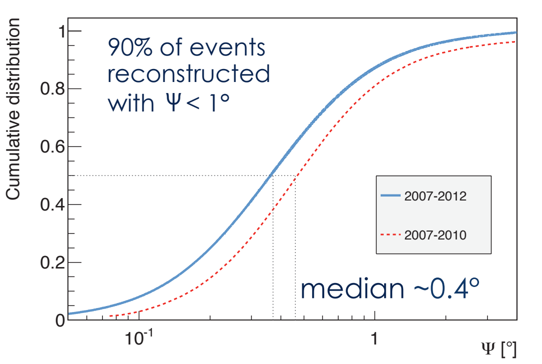
The ANTARES search for point-like ν sources

First time-integrated search with 2007-2010 data (813 days) **ApJ. 760:53 (2012)**

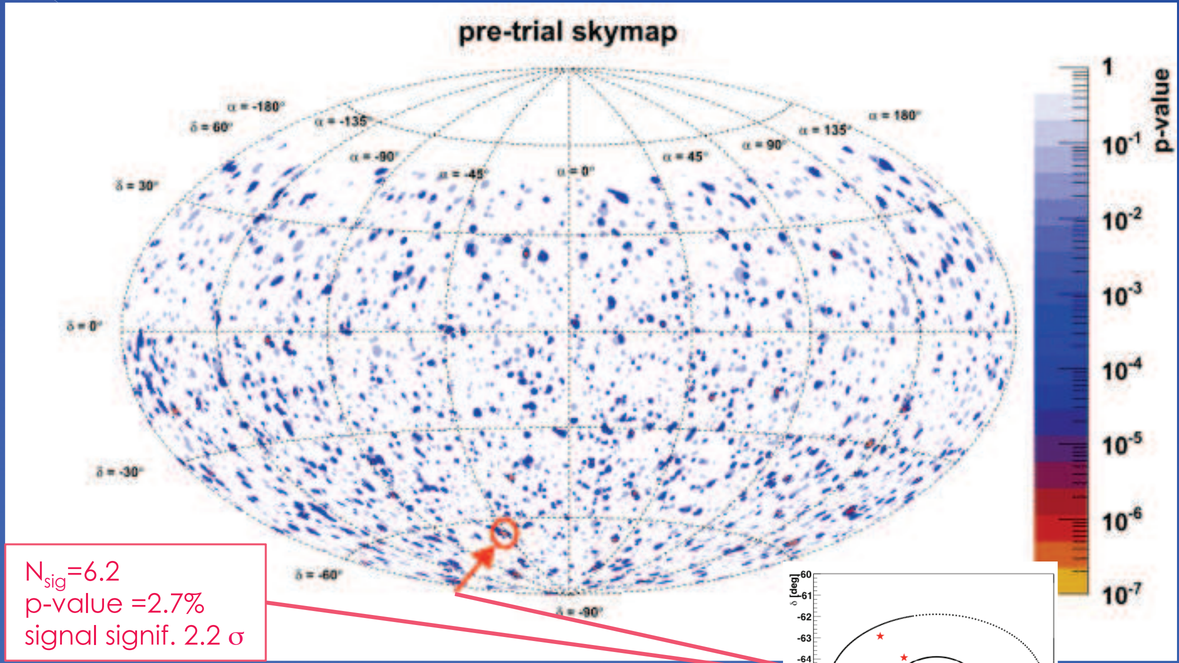
- 3058 neutrino candidates (atmospheric + astrophysical ??)
- No statistically significant excess
- The "best cluster" (-46.5°, -65.0°) compatible with the background hypothesis, p=0.026 (no known source there from ROSAT, Fermi-LAT/HESS)

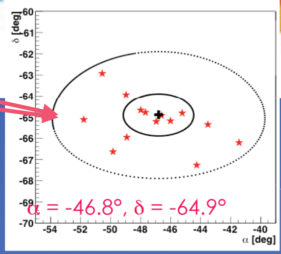
New search on bigger data sample: 2007-2012 data (1340 days) **ApJ-L. 786:L5 (2014)**

- **5516** neutrino candidates (improved angular resolution)



cumulative distribution of the angular resolution for selected events assuming E^{-2} spectrum





- again no statistically significant excess observed
- **The same "best cluster"** with 6 new events (14 total in 3° search cone) observed **but compatible with background hypothesis** (p=2.1%)

The ANTARES search for ν from known γ sources

Using the 2007-2012 data (1340 days) we counted the number of events in a 20° cone around a list of pre-selected candidates, searching for an excess over the background. Assuming a neutrino flux from the source like **$d\phi_\nu/dE_\nu = \Phi_0 E_\nu^{-2}$** in absence of a statistically significant excess we can put a limit (at 90% C.L.) on **Φ_0** . Few examples

source	α_s [°]	δ_s [°]	n_s	p-value	$\Phi_\nu^{90\%\ C.L.}$
HESSJ0632+057	98.24	5.81	1.60	0.0012	4.40
HESSJ1741-302	−94.75	−30.20	0.99	0.003	3.23
3C279	−165.95	−5.79	1.11	0.01	3.45
HESSJ1023-575	155.83	−57.76	1.98	0.03	2.01
ESO139-G12	−95.59	−59.94	0.79	0.06	1.82
CirX-1	−129.83	−57.17	0.96	0.11	1.62
PKS0548-322	87.67	−32.27	0.68	0.10	2.00
GX339-4	−104.30	−48.79	0.50	0.14	1.50
VERJ0648+152	102.20	15.27	0.59	0.11	2.45
PKS0537-441	84.71	−44.08	0.24	0.16	1.37
MGROJ1908+06	−73.01	6.27	0.21	0.14	2.32
Crab	83.63	22.01	0.00	1.00	2.46

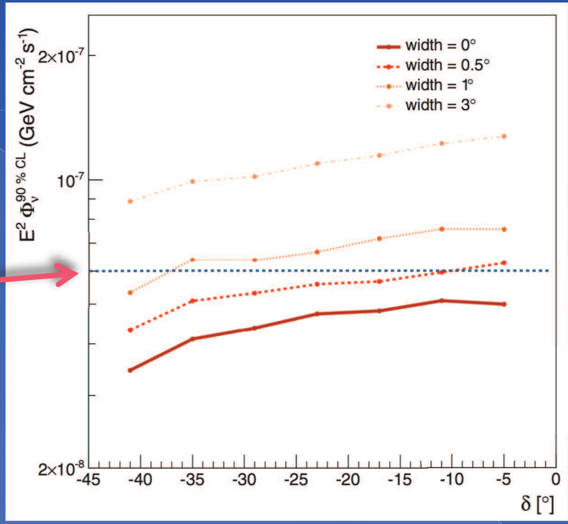
$\times 10^{-8}$ GeV cm^{-2} s^{-1}

ApJ-L. 786:L5 (2014)

Is there a point-like ν source close to the Galactic Center (α =-79°, δ =-23°, Gonzalez-Garcia et al. arXiv 1310.7194) such that could explain the recent IceCube evidence ???

The expected flux should have Φ_0 =6•10^{-8} GeV cm^{-2} s^{-1}

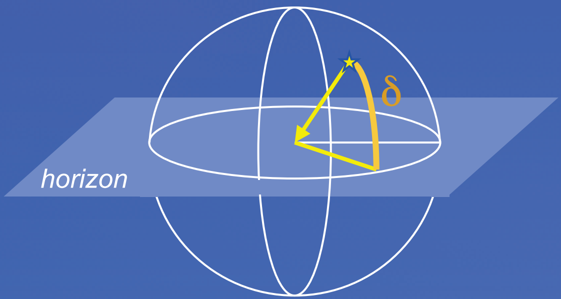
The point like hypothesis as well as extended Gaussian like extended (0.5°, 1° and 3°) sources have been tested: no excess found. No evidence found for a point like-source that could explain the IceCube results

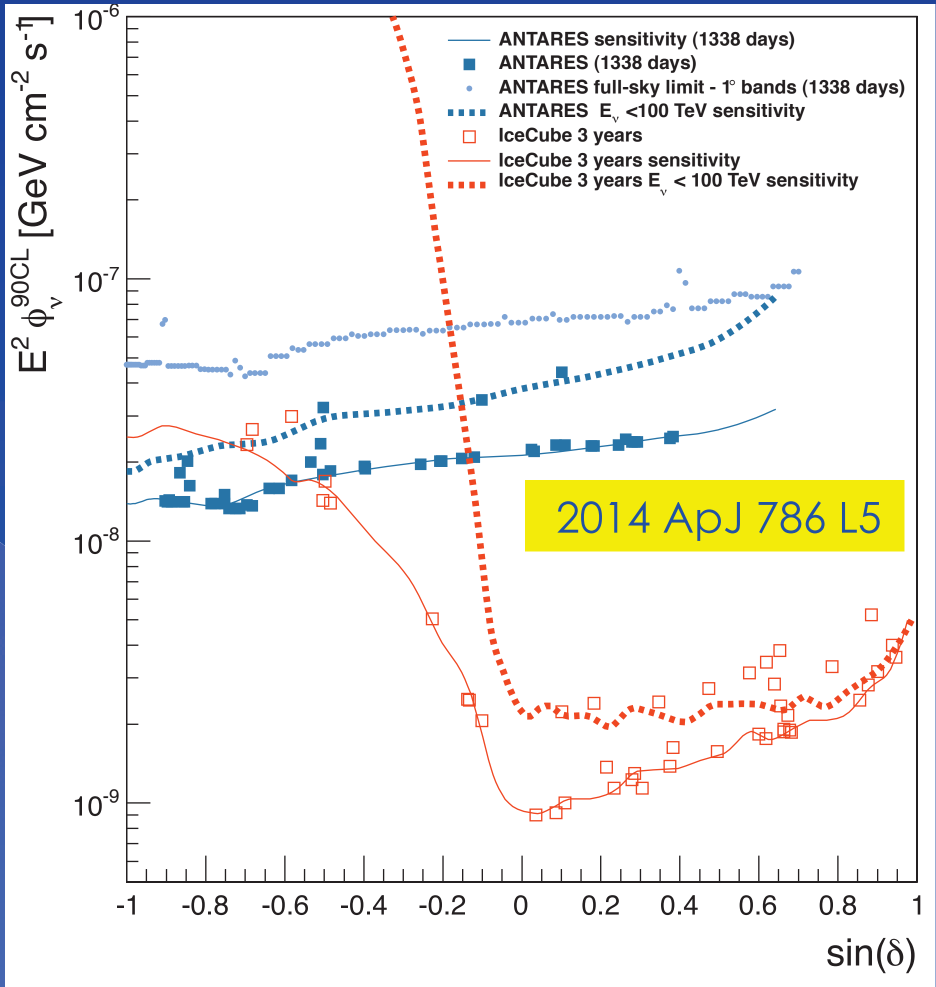


ANTARES search for ν point-like sources

ANTARES data provide the most stringent limits to flux of neutrinos from point-like sources for a large part of the Southern Sky in the TeV region.

IceCube sensitivity to point-like sources in the Southern Sky improves for E_ν > 100 TeV



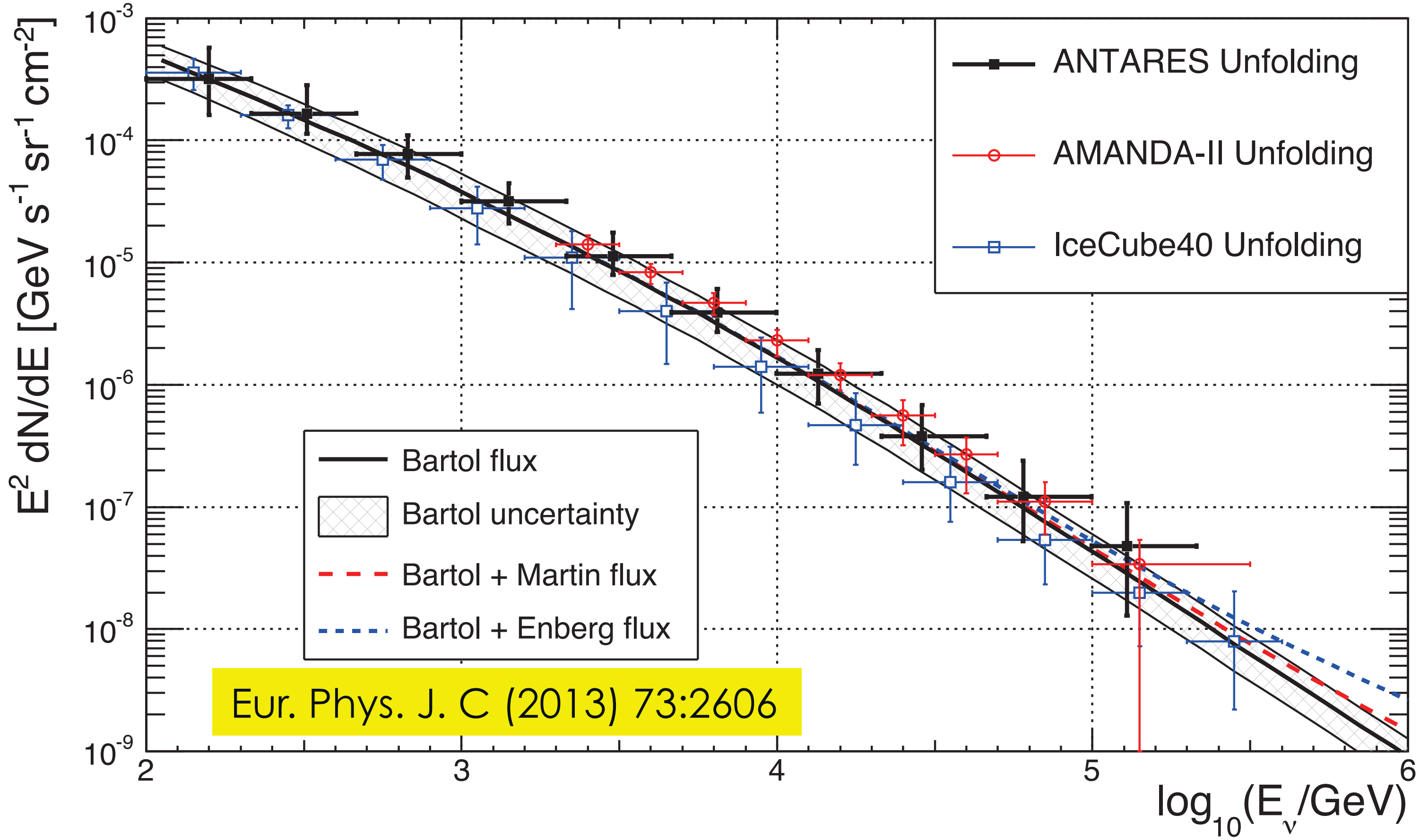


90 % C.L. flux upper limits and sensitivities on the muon neutrino flux for six years of ANTARES data. IceCube results are also shown for comparison.

Study of the atmospheric $\nu_\mu + \bar{\nu}_\mu$ spectrum

Atmospheric neutrinos are the irreducible background for the search of the astrophysical neutrino flux: big uncertainty in present spectra parameterizations. The unfolded spectrum, for 100 GeV < E_ν < 200 TeV well described by

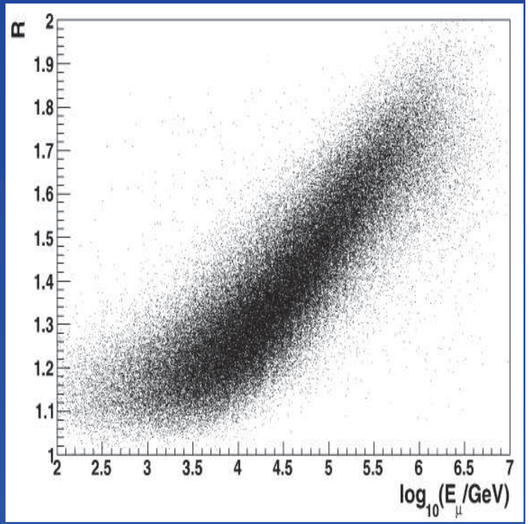
$$\frac{dN_{\nu_\mu+\bar{\nu}_\mu}}{dE_\nu} \propto E_\nu^{-\gamma} \quad \text{and} \quad \gamma = 3.58 \pm 0.12$$



Eur. Phys. J. C (2013) 73:2606

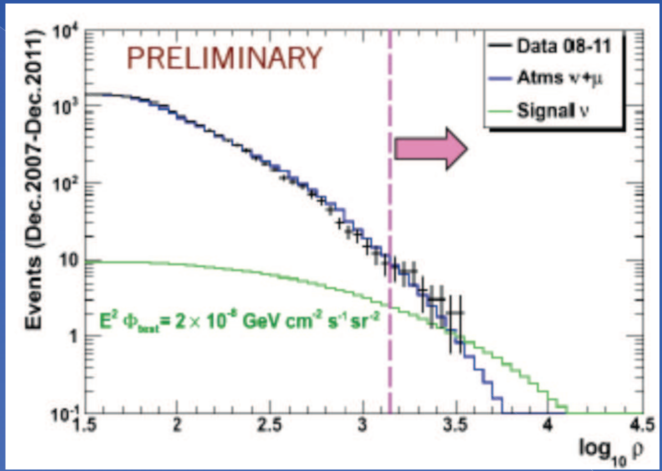
Search for a flux of ν_μ astrophysical neutrinos from diffuse sources

Search for an excess in the energy spectrum of up-going tracks with respect to the expected distribution due to atmospheric neutrino.
A good energy estimator is needed.



- First search with 2008-2009 data (334 days) **Phys. Lett. B 696 (2011) 16-22**
  - Energy estimator "R": the mean number of hits collected by fired PMTs
  - n_{obs} = 9 "candidate" events observed with n_{bkg} =10.7 background for 20 TeV < E_ν < 2.5 PeV

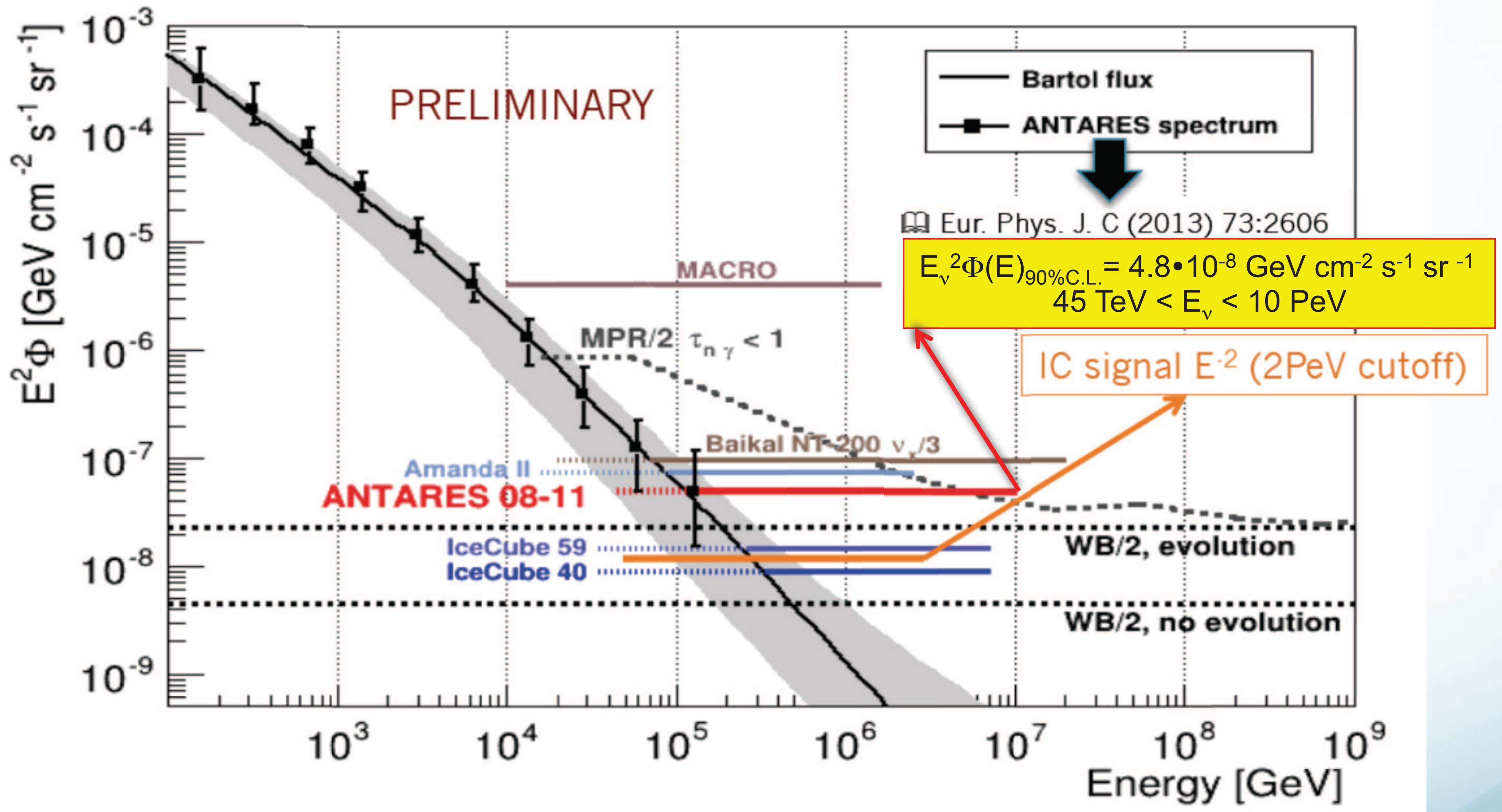
→ $E_\nu^2\Phi(E)_{90\%C.L.}$ = 5.3•10^{-8} GeV cm^{-2} s^{-1} sr^{-1}



- New search with 2008-2011 data (885 days)
  - Energy estimator: dE/dx
  - Reduced atmospheric muon contamination (<0.4%)
  - n_{obs} = 8 "candidate" events with n_{bkg} =8.4
  - n_{sig} =2.3 for 45 TeV < E_ν < 10 PeV

→ $E_\nu^2\Phi(E)_{90\%C.L.}$ = 4.8•10^{-8} GeV cm^{-2} s^{-1} sr^{-1}

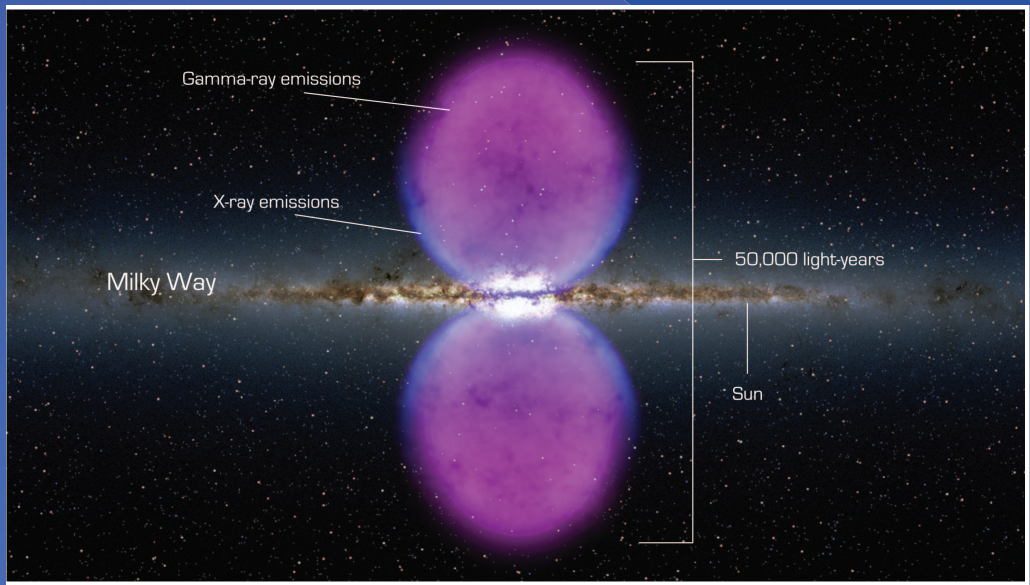
Search for a flux of ν_μ astrophysical neutrinos from diffuse sources



Neutrinos from "FERMI Bubbles" ??

Search possible for a Mediterranean Cherenkov ν Telescope

- FERMI detected hard γ emission (E^{-2}) up to 100 GeV in extended "bubbles" around Galactic Center, hard spectrum not compatible with Inverse Compton mechanism, M.Su et al., Ap.J.724 (2010).
- Models involving hadronic processes (e.g. Crocker & Aharonian, PRL 2011) predict significant neutrino fluxes.
- Estimates for the neutrino flux: $\Phi_\nu \approx 0.4 \cdot \Phi_\gamma \Rightarrow \quad E_\nu^2 \frac{dN_{\nu_\mu+\bar{\nu}_\mu}}{dE_\nu} \approx 1.2 \div 2.4 \cdot 10^{-7} GeV\ cm^{-1} s^{-1} sr^{-1} = A_{theory}$
- An exponential energy cut-off could affect the flux $E_\nu^2 \frac{dN_{\nu_\mu+\bar{\nu}_\mu}}{dE_\nu} = A_{theory} e^{-\frac{E}{E_\nu^{cutoff}}}$
- ANTARES, the present Mediterranean ν Telescope, searched for these neutrinos.



Search for a diffuse ν_μ flux from "FERMI Bubbles"

Compare the neutrino-like events coming from 3 "off-zones" (with the same size and shape as the Fermi Bubbles "on-zone") with the events coming from the Fermi Bubbles

Events selected as up-going and well reconstructed tracks.
Data sample, in the period 2008-2011, includes 806 days

In the 3 off-zones observed:

n_{bkg} = 9, 12 and 12 events

In the Fermi-Bubble **region**

n_{obs} = 16 events (1.2σ excess)

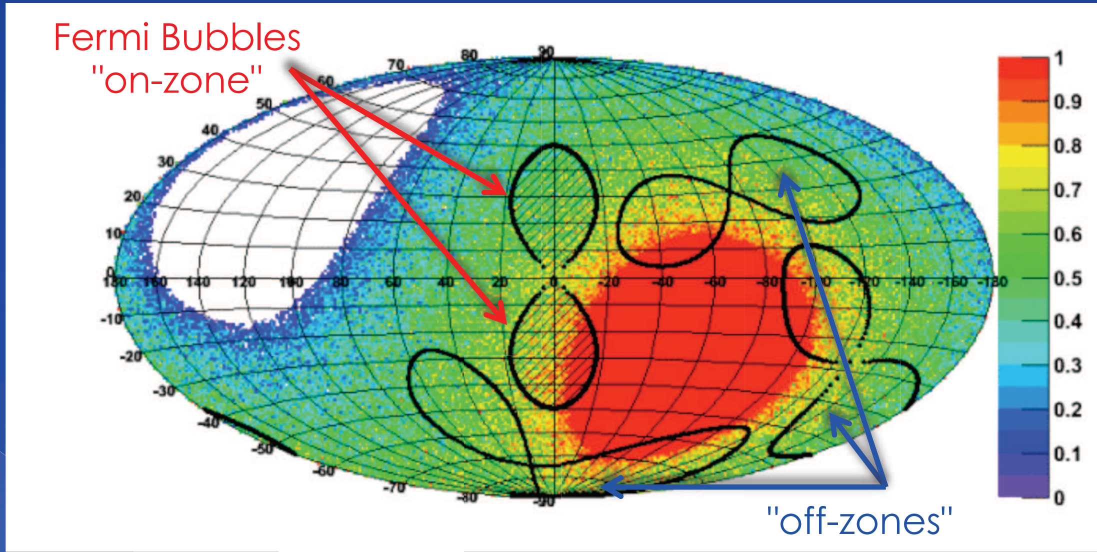
No statistically consistent signal observed

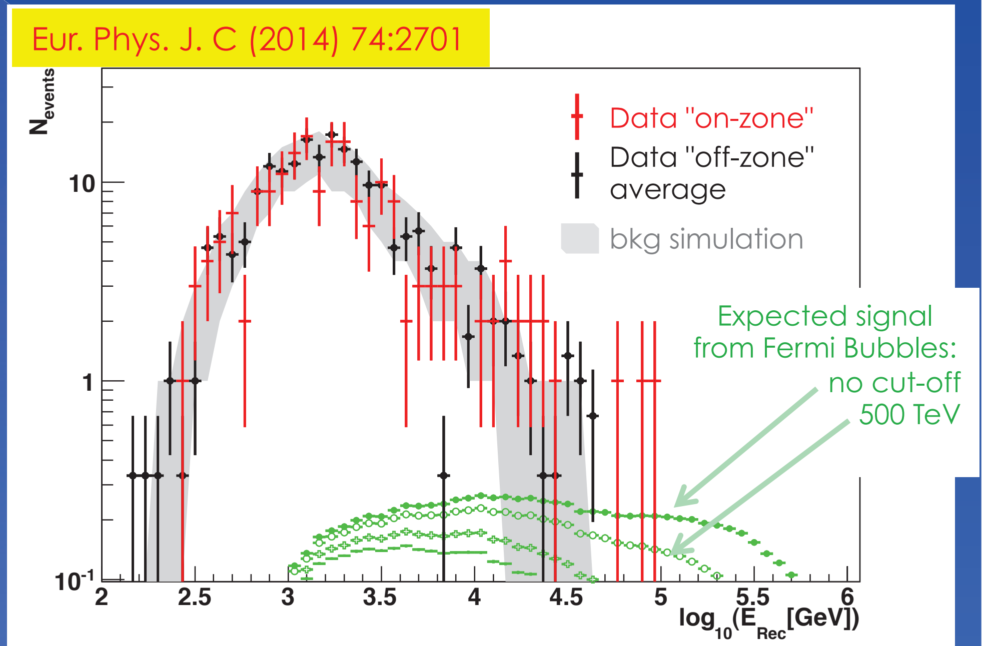
Assuming no cut-off

$E^2\Phi(E)_{90\%C.L.} = 5.7 \cdot 10^{-7}$ GeV cm^{-2} s^{-1} sr^{-1}

Assuming 500 TeV cut-off

$E^2\Phi(E)_{90\%C.L.} = 8.7 \cdot 10^{-7}$ GeV cm^{-2} s^{-1} sr^{-1}





ANTARES - Multi-Messenger Searches

Potential astrophysical sources are predicted to emit very faint neutrino signal. The Multi-Messenger Approach increases the **discovery potential**, by observing with different probes; the **significance**, by coincident detection; the **efficiency**, by relaxed cuts.

ANTARES ⟺ VIRGO
LIGO

common working group (GWHEN)
5 Line data
S. Adrián-Martínez et al.,
JCAP 06 (2013) 008

ANTARES ⟺ AUGER

Adrian-Martinez et al.,
ApJ 774 (2013) 008

Flaring sources
(ν emission from γ-flaring blazars/microquasars)

ANTARES ⟺ FERMI
SWIFT
RXTE

APP 36 (2012) 204

arXiv:1402.1600v1

TAToO
(Telescopes – ANTARES Target of Opportunity)

Optical follow-up of **neutrino alerts** for transient source search (GRBs, SNae).
Analysis in progress!

ANTARES ⟺ Optical Telescopes
TAROT & ROSTE + more

Ageron *et al.*, *Astrop.Phys* 35 (2012) 530-536

GCN
(**GRB** Coordinat. Network)

ANTARES ⟺ GCN

1.S. Adrián-Martínez et al.,
JCAP 1303 (2013) 006

A Multi-Messenger Search of ν from GRB

GCN alerts trigger the recording of all the low level triggers. A continuous buffer ensures the availability of the data before the alert

GCN=Gamma Ray Burst Coordination Network

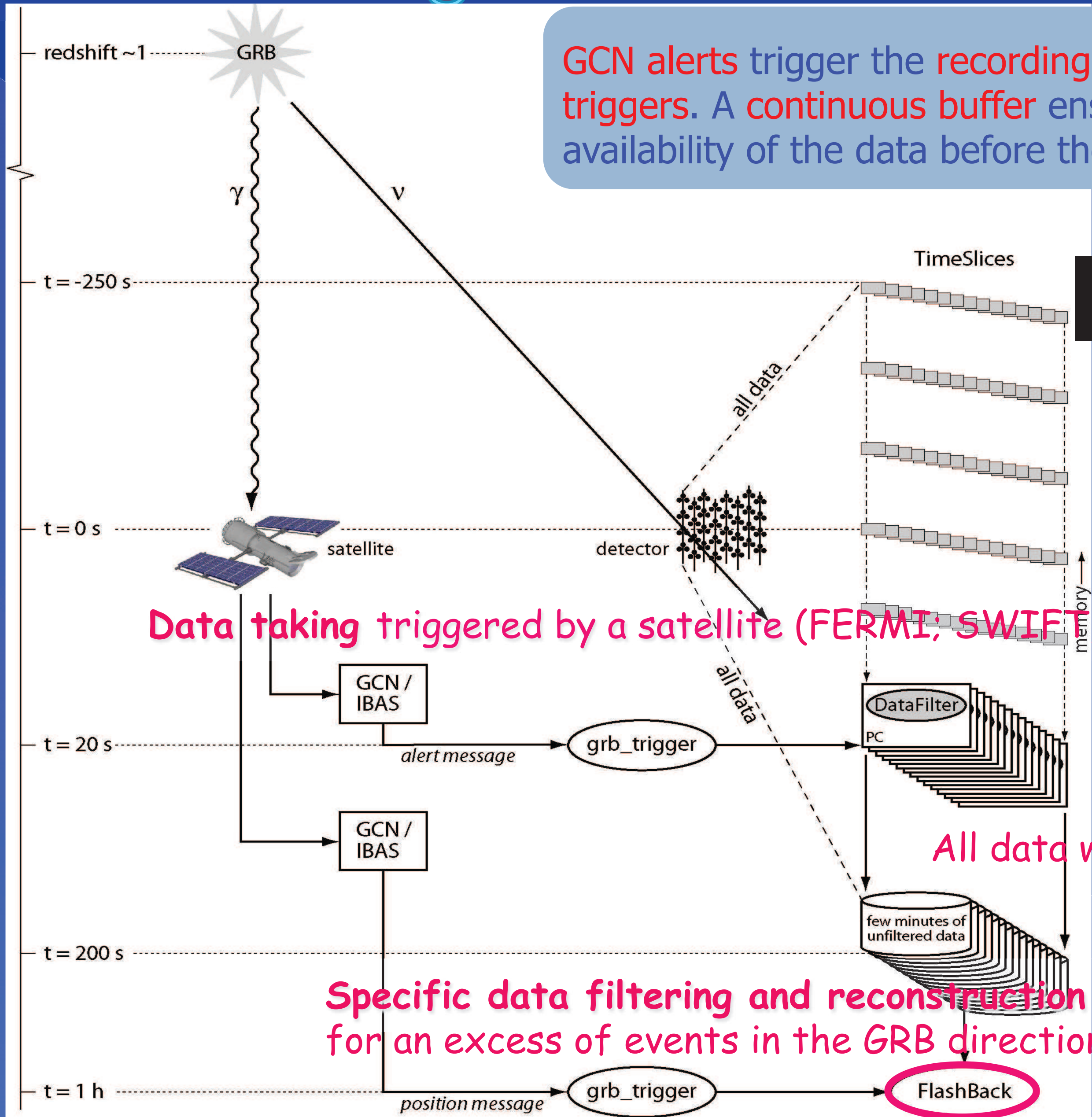
t =-250 s

t = 0 s

t = 20 s

t = 200 s

t = 1 h



Data taking triggered by a satellite (FERMI; SWIFT, INTEGRAL)

All data written to disk

Specific data filtering and reconstruction by searching for an excess of events in the GRB direction (offline)

A Multi-Messenger Search of ν from GRB

Astronomy & Astrophysics 559, A9 (2013)

2007-2011 data:

- alerts and data from FERMI – SWIFT - GCN
- analysis of 296 long GRBs (total prompt emission 6.6 hours)

Simulation of neutrino fluxes from GRB:

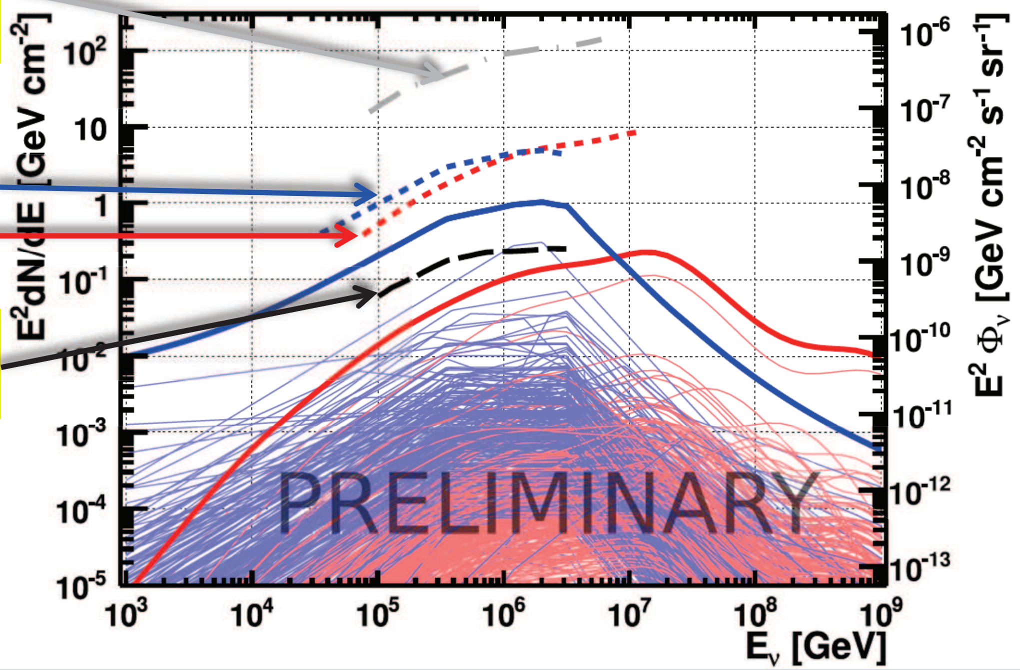
- NeuCosmA (Hümmer et al 2010) → expected 0.061 events
- Guetta (Guetta et al. 2004) → expected 0.48 events
- Expected background 0.051 events

No events found in stacked GRB search within 10° window:

Previous ANTARES result, 40 GRBs
JCAP 1303 (2013) 006

ANTARES upper limits 90% C.L. for
Guetta fluxes
NeuCosmA fluxes

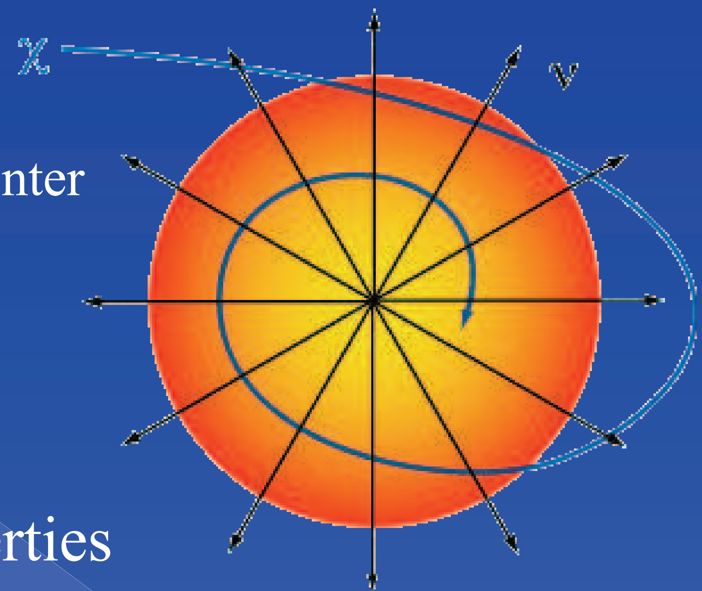
IceCube upper limits 90% C.L.
IC40+59 for 215 GRBs



... not only neutrino astrophysics...

... also open problems in particle physics ...

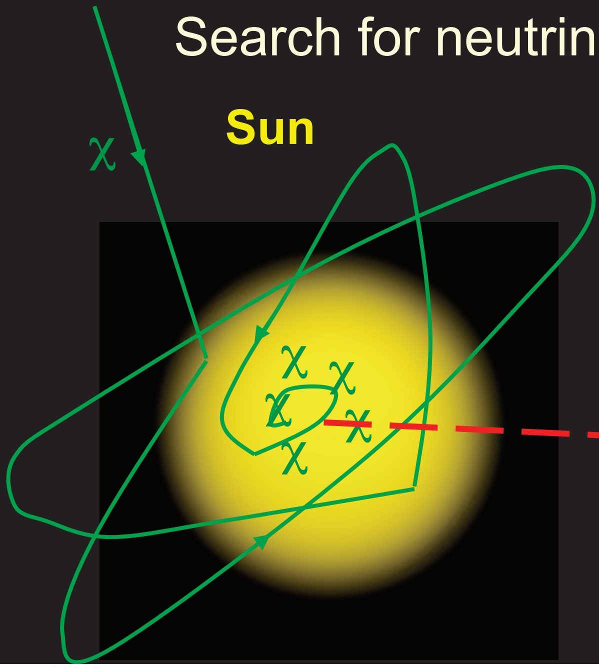
- Dark Matter searches:
  - Neutralinos from Sun, Earth, Galactic Center
- Monopoles, Nuclearites
- Acceleration mechanisms
- Neutrino interaction Cross sections
- Neutrino oscillations, neutrino properties
- …



Neutralino search: $\chi\chi \rightarrow \nu + \ldots$

ANTARES: indirect search for Dark Matter

Search for neutrinos from dark matter annihilations in the Sun

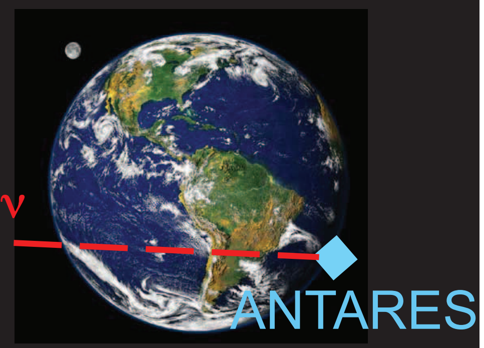


WIMPs gravitationally trapped via elastic collisions in the sun

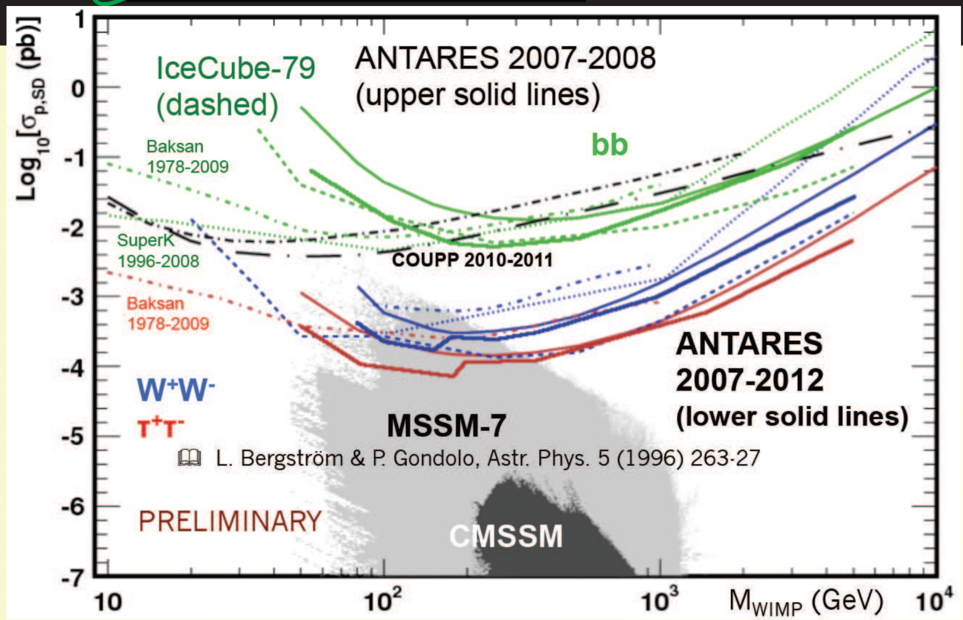
$\chi\ \chi \rightarrow WW,\ ff$

$W, f \rightarrow \nu\ X$

Earth



$\langle E_\nu \rangle \sim M_\chi/3$

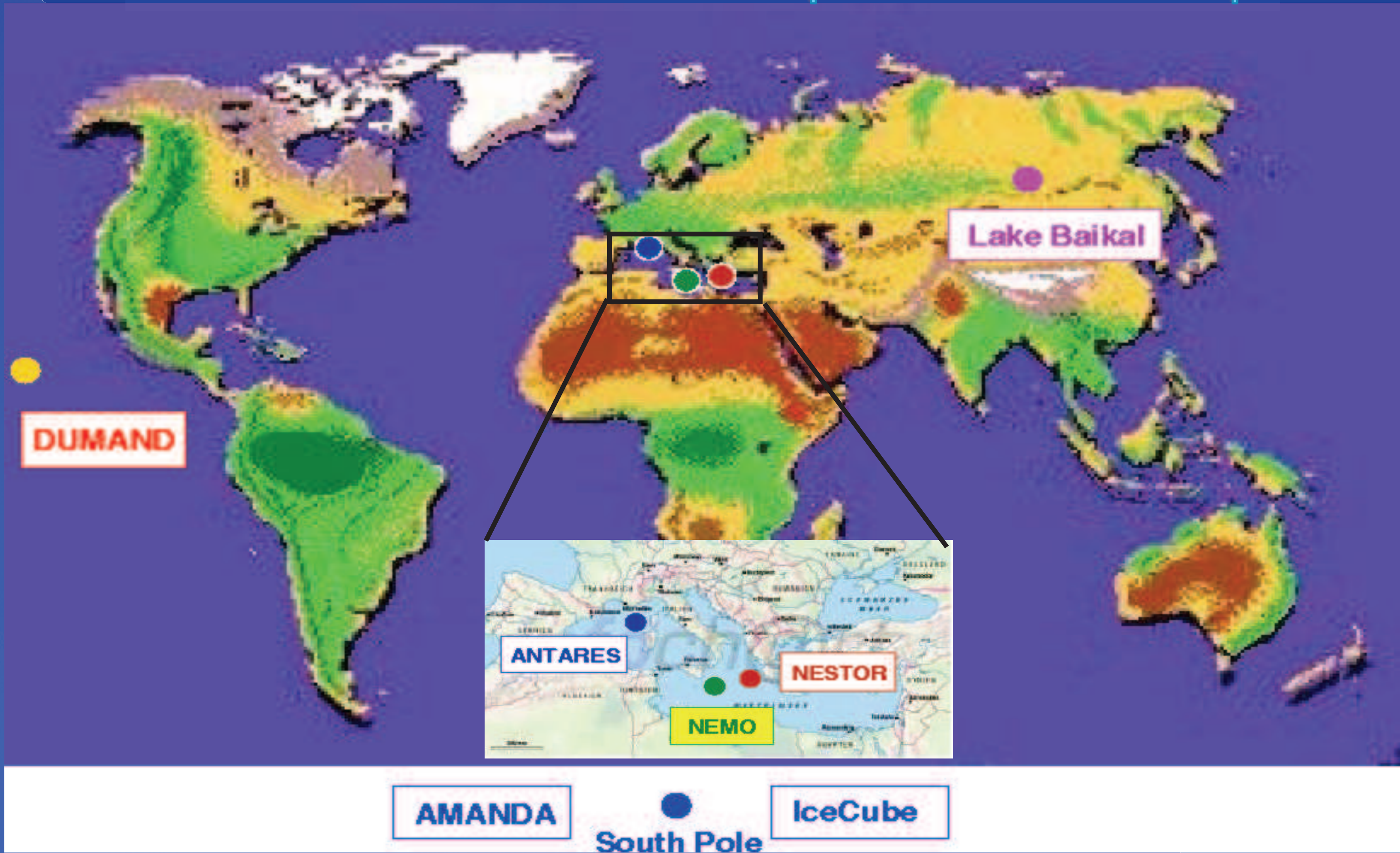


Previous ANTARES result 2007-2008 (168 days)
New improved analysis 2007-2012 (1321 days)

- Optimization for best sensitivity for each M_{WIMP}
  - Track fitting quality
  - Two independent reconstruction algorithms
  - Search cone size
- Background by scrambled data in the Sun direction
- Single line and Multi-line events used

Journal of Cosmology and Astroparticle Physics
JCAP11(2013)032

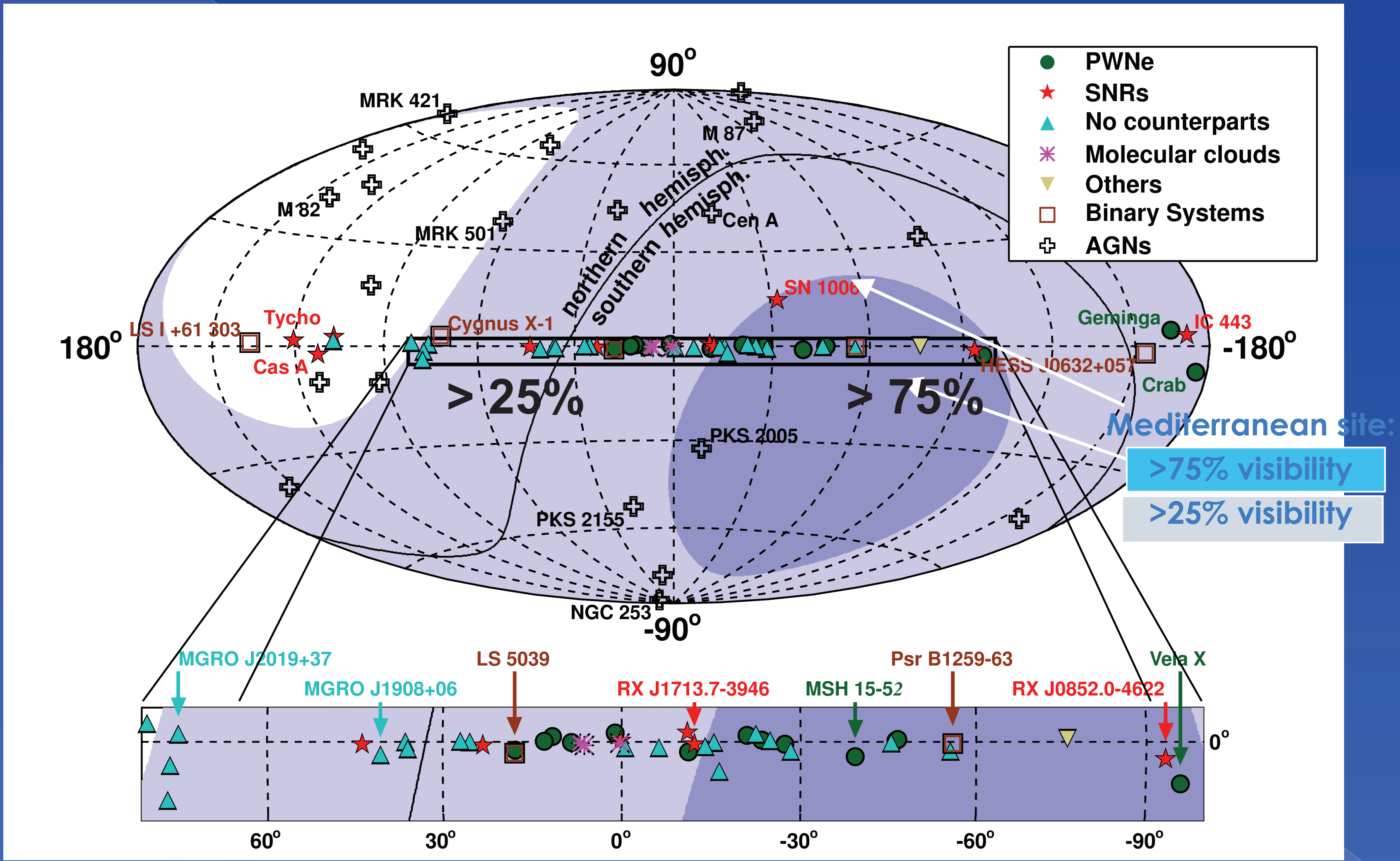
The Neutrino Telescope World Map



ANTARES + NEMO + NESTOR joined their efforts to prepare a km^3-scale Cherenkov neutrino telescope in the Mediterranean → **KM3NeT Collaboration**

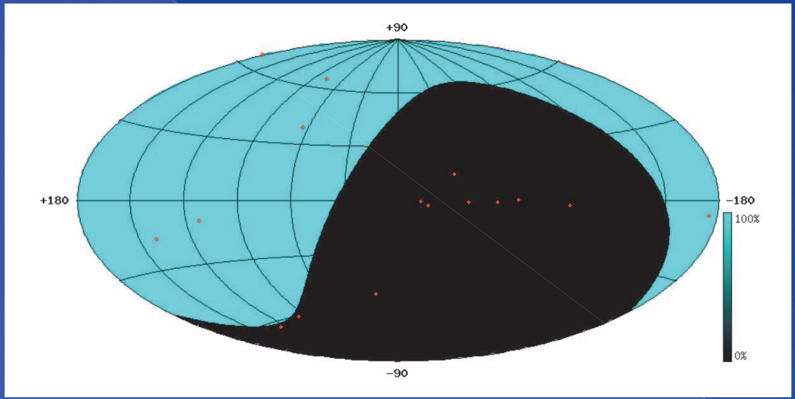
Mediterranean Sea ν Telescope Sky Coverage

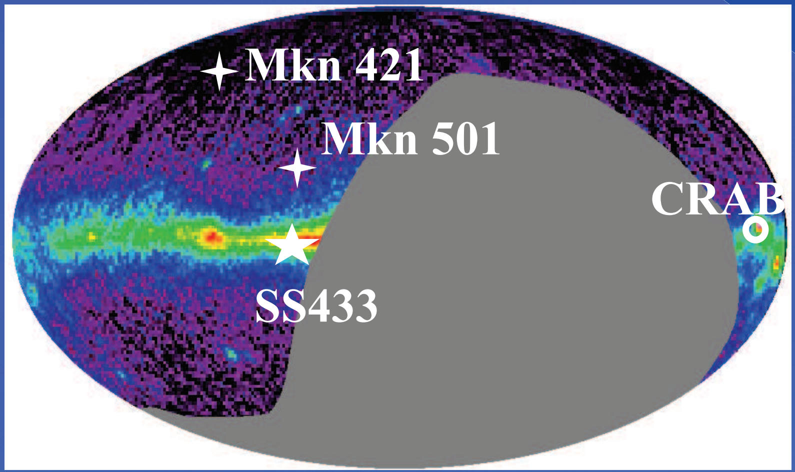
Observable sky, galactic coordinates, for a detector efficient to tracks from below the horizon (up-going tracks). Mediterranean location provides a 3 π sr sky coverage, 0.5 π sr instantaneous common view with IceCube, and about 1.5 π sr common view per day. The Galactic centre is visible 2/3 of the time.



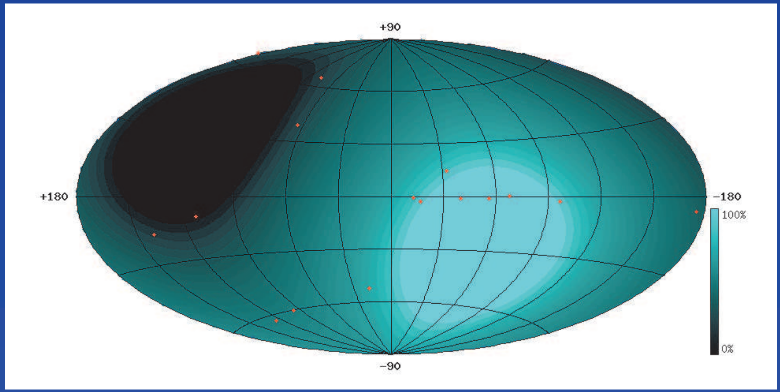
Locations for Neutrino Astronomy

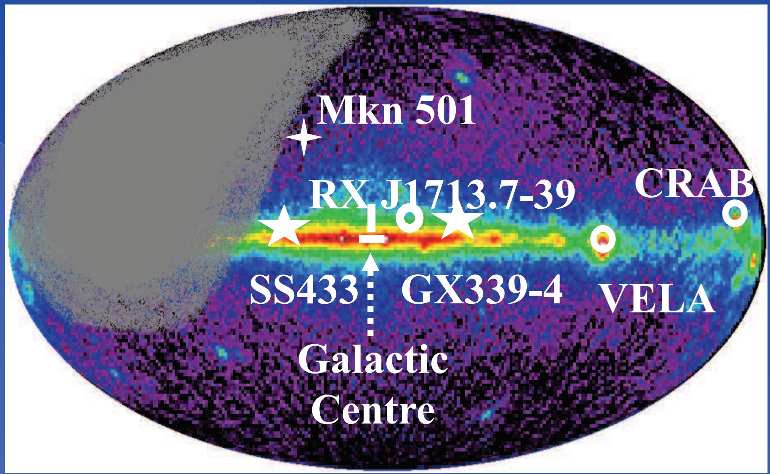
From Antartica





From Mediterranean Sea



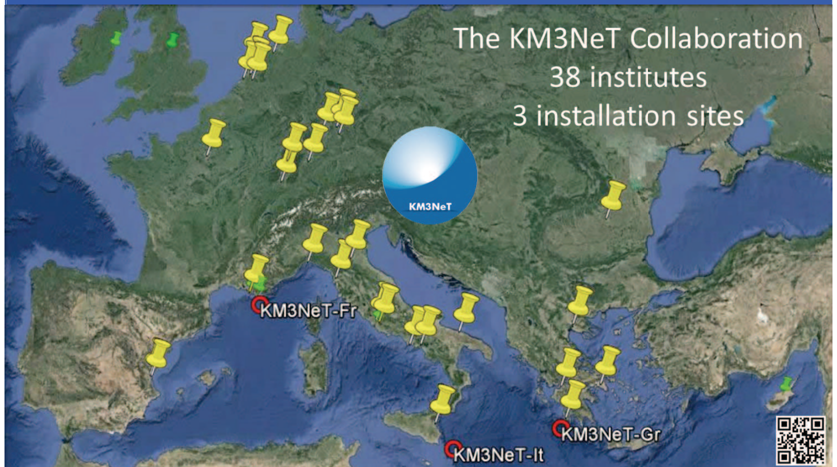


A Km^3 Neutrino Telescope in Mediterranean Sea will be complementary to IceCube and … will search for neutrino sources also in the Galactic centre

International Collaboration involving 241 scientists from 38 Institutes and 10 EU countries (CY, DE, ES, FR, GR, IE, IT, NL, RO, UK)

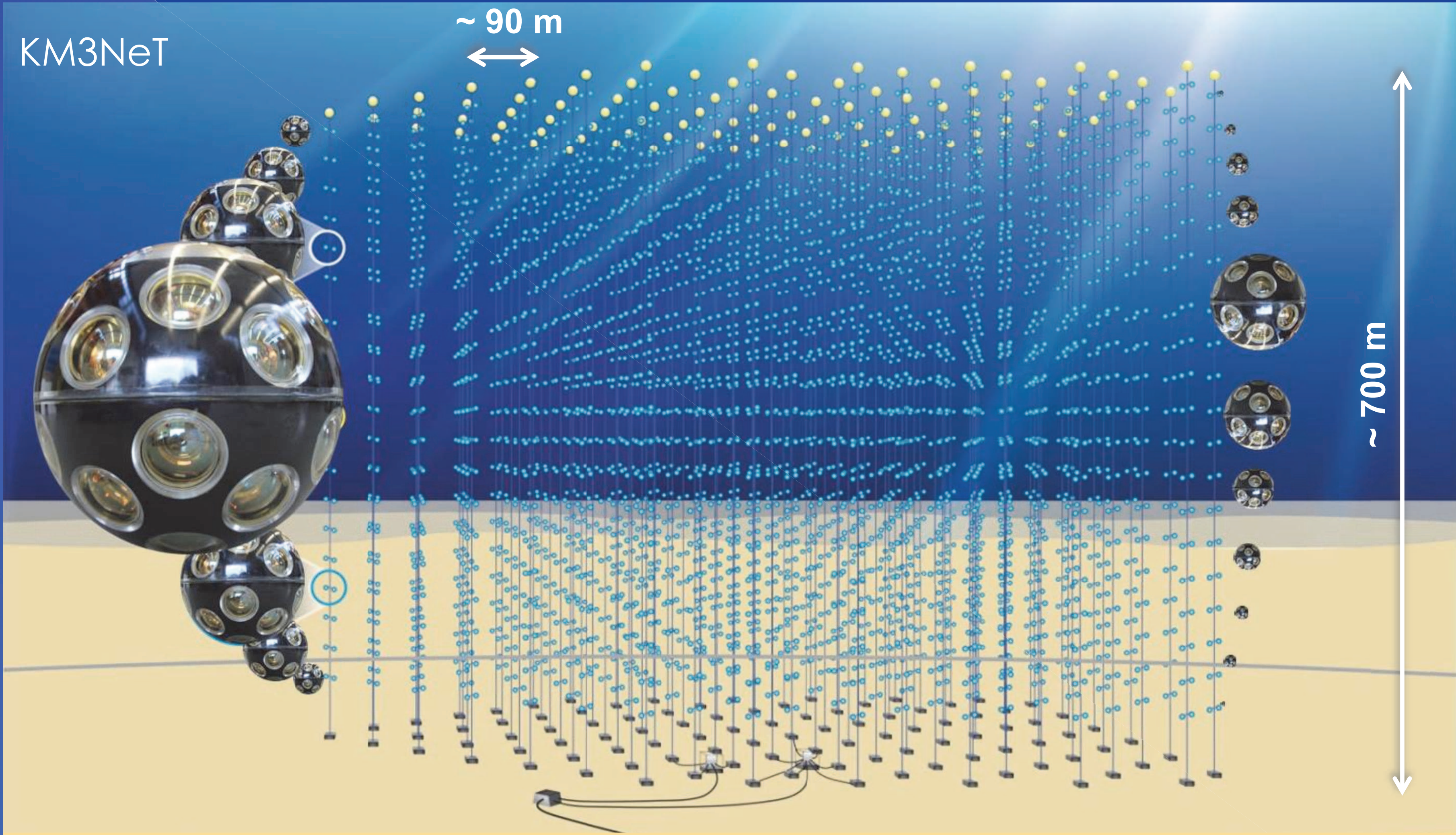
KM3NeT

- Objective: to build the most sensitive high energy neutrino telescope in the Northern Hemisphere
- KM3NeT is on the ESFRI roadmap since 2006



The KM3NeT Detector

TDR : ISBN 978-90-6488-033-9 (2010)



About 11000 KM3NeT-DOMs (Digital Optical Modules) attached to about 600 KM3NeT Detection Units

Propriety KM3NeT Collaboration

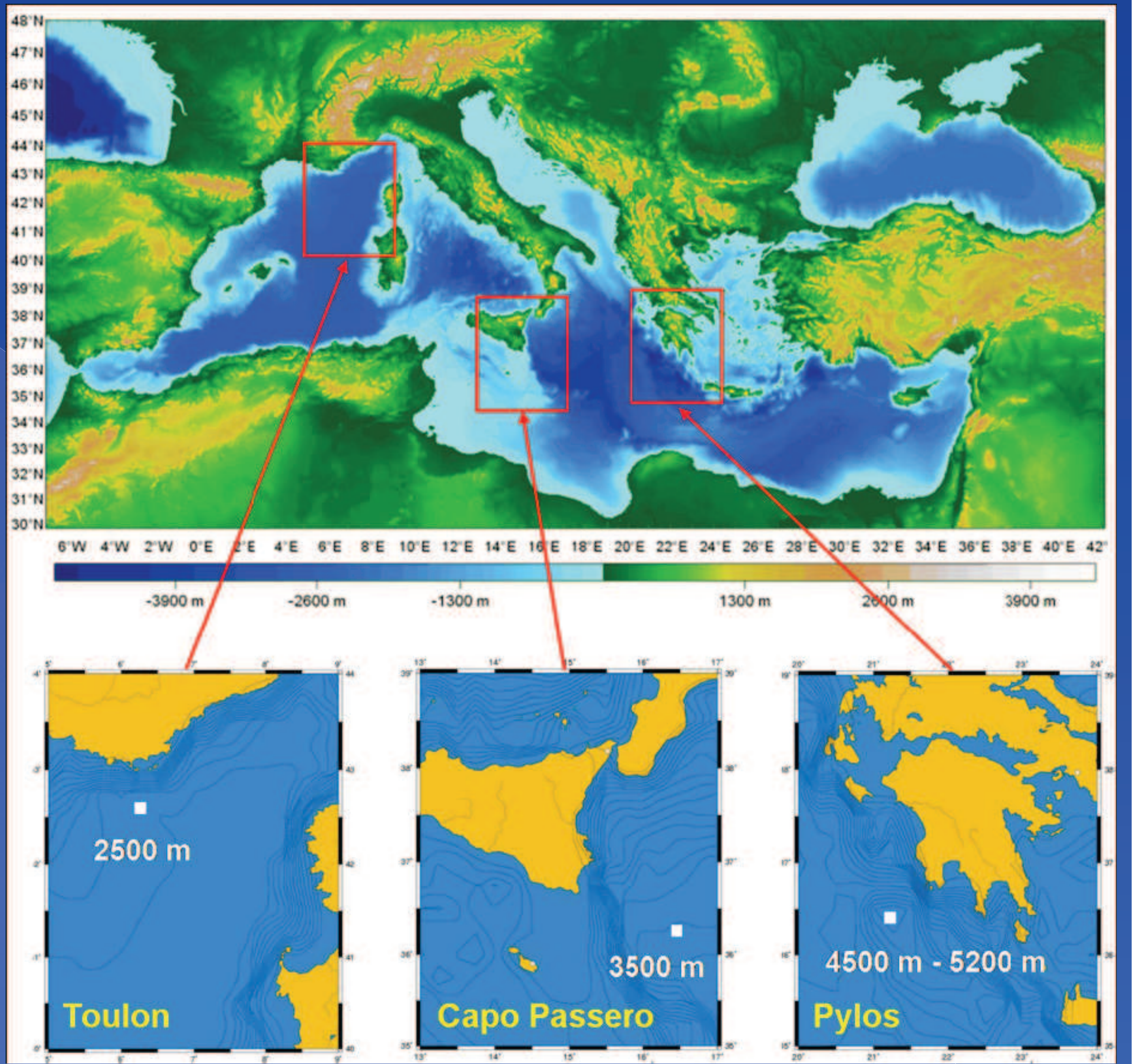
18 optical modules per detection unit

First optical module above seabed ~ 100m

Distance between optical modules ~ 36 m

KM3NeT multisite construction

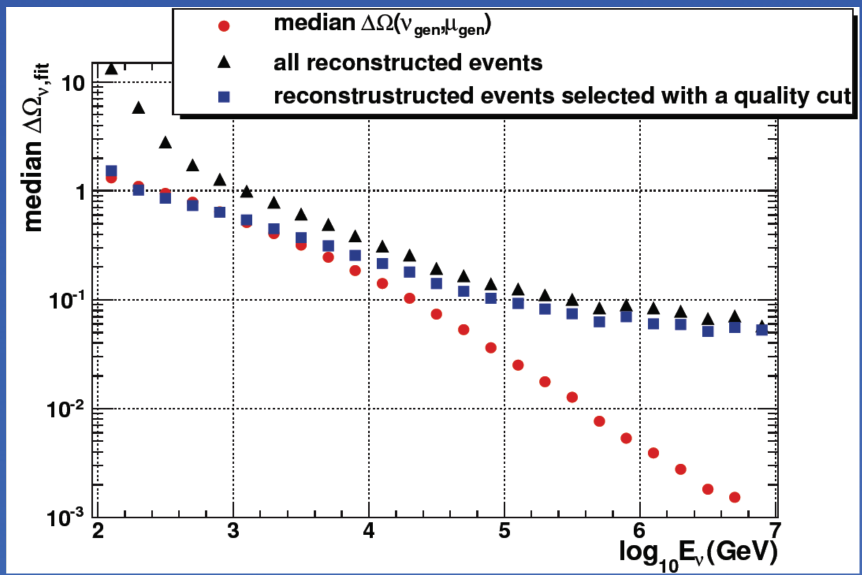
- 3 detectors, each ~2km^3 in 3 sites
- KM3NeT-France:
  Toulon (depth ~ 2500m)
- KM3NeT-Italy:
  Capo Passero (depth ~ 3500m)
- KM3NeT-Greece:
  Pylos (depth ~ 4500m)
- Common hardware, data handling and operation control
- Centrally managed
- Node for marine science at each installation site

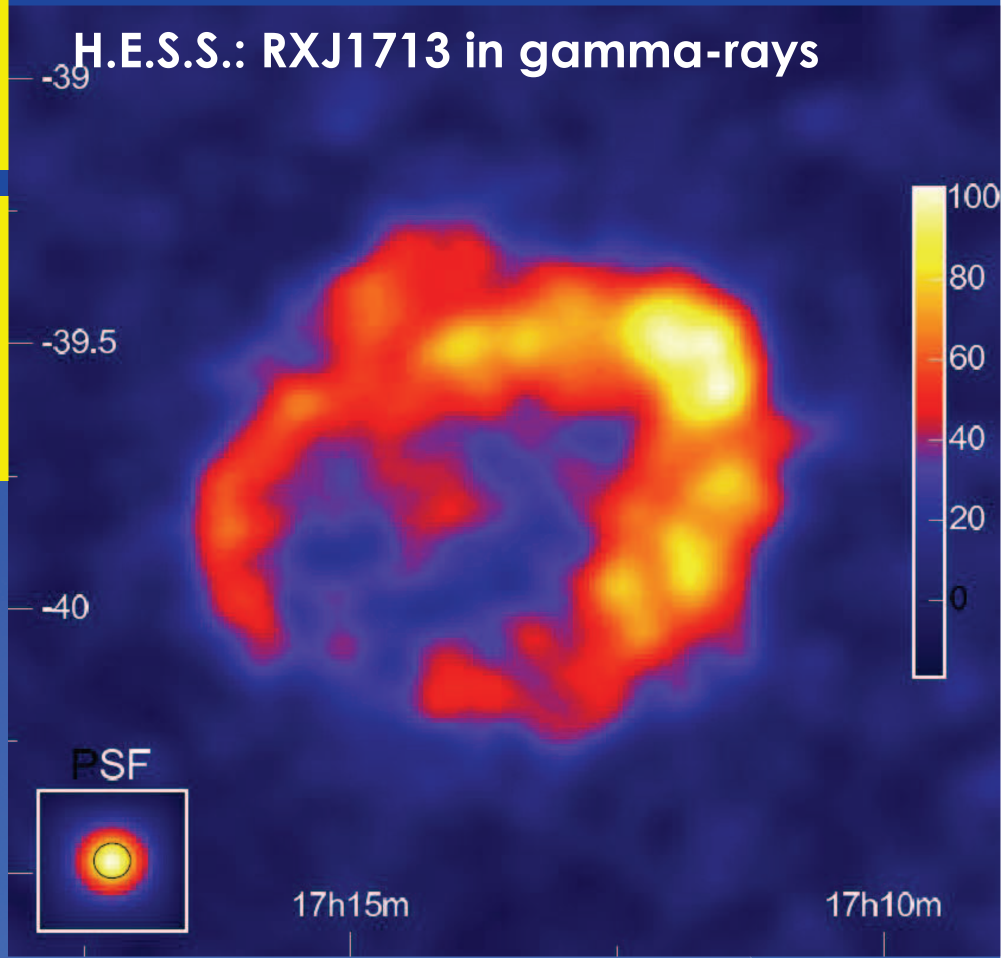


Sensitivity to galactic source for a Mediterranean ≈5km^3 Cherenkov ν Telescope

For the galactic PWN VelaX:
- 5σ discovery in ~ 3 years (50% prob.)
- evidence (3σ 50% prob.) in ~1.2 years

For the galactic Supernova Remnant: RXJ1713.7-3946
- 5σ discovery in ~5 years (50% prob.)
- evidence (3σ 50% prob.) in 2 years

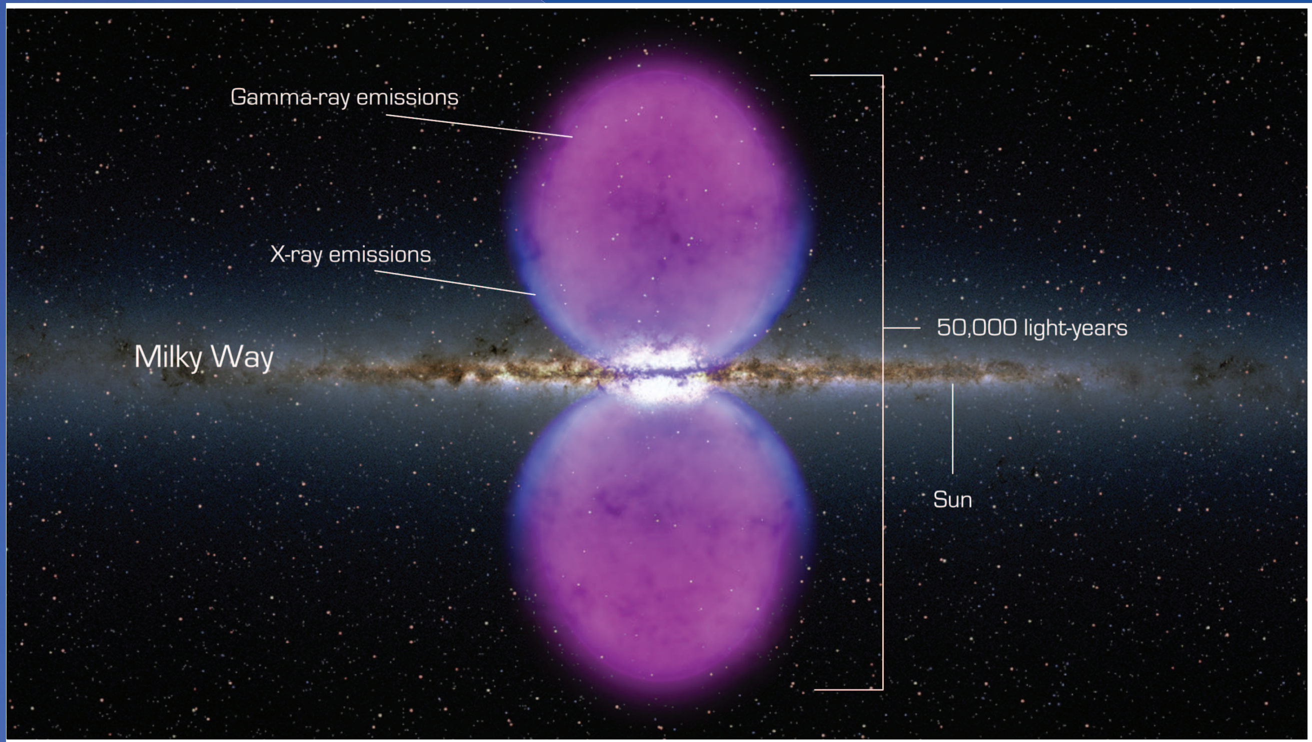




Neutrinos from "FERMI Bubbles" ??

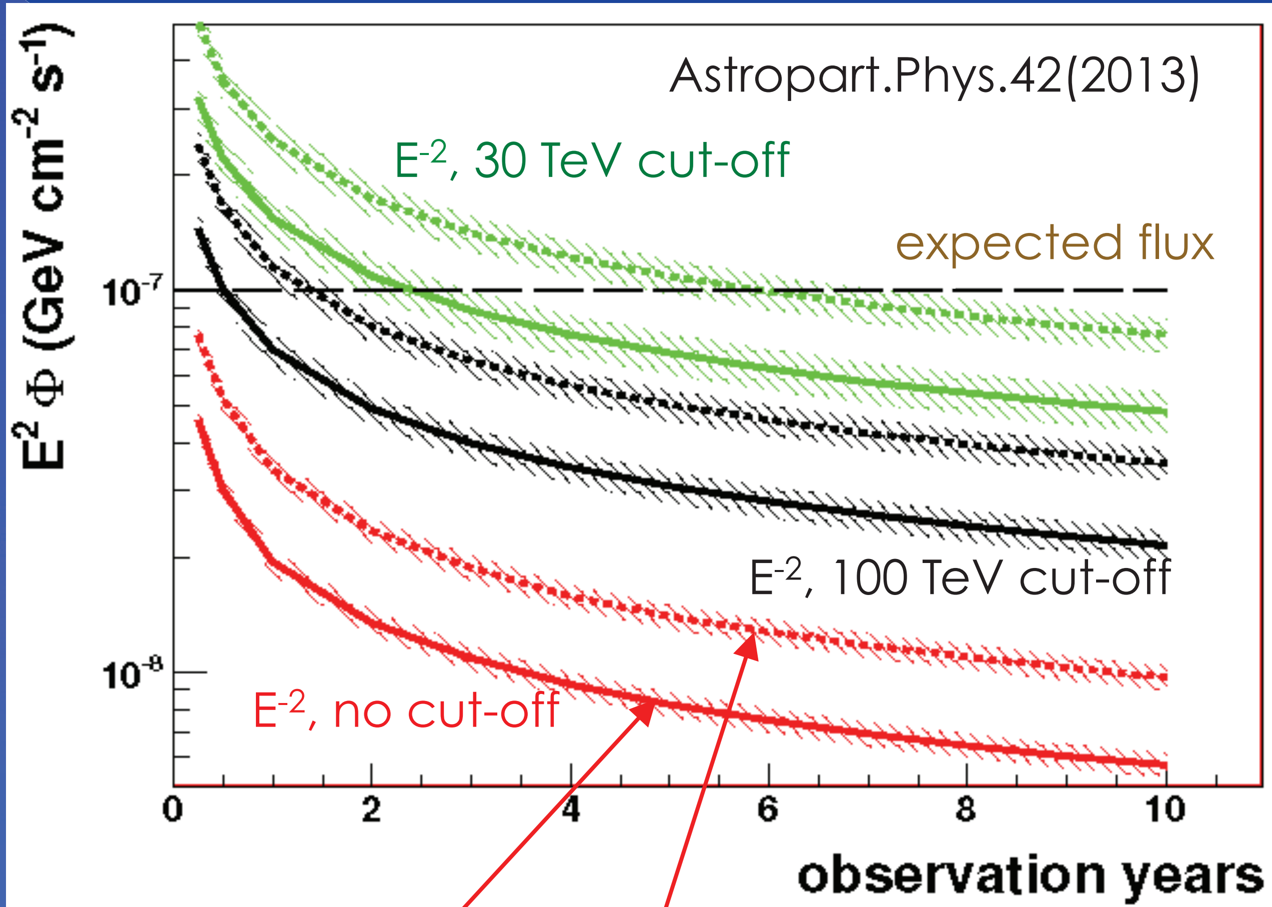
Search possible for a Mediterranean Cherenkov ν Telescope

- FERMI detected hard γ emission (E^{-2}) up to 100 GeV in extended "bubbles" around Galactic Center, hard spectrum not compatible with Inverse Compton mechanism, M.Su et al., Ap.J.724 (2010).
- Models involving hadronic processes (e.g. Crocker & Aharonian, PRL 2011) predict significant neutrino fluxes.
- This could be one of the first neutrino "source" for the Mediterranean ν Telescope.



KM3NeT Sensitivity to H.E. ν from "FERMI Bubbles"

for a ≈ 5km^3 Mediterranean Cherenkov ν Telescope

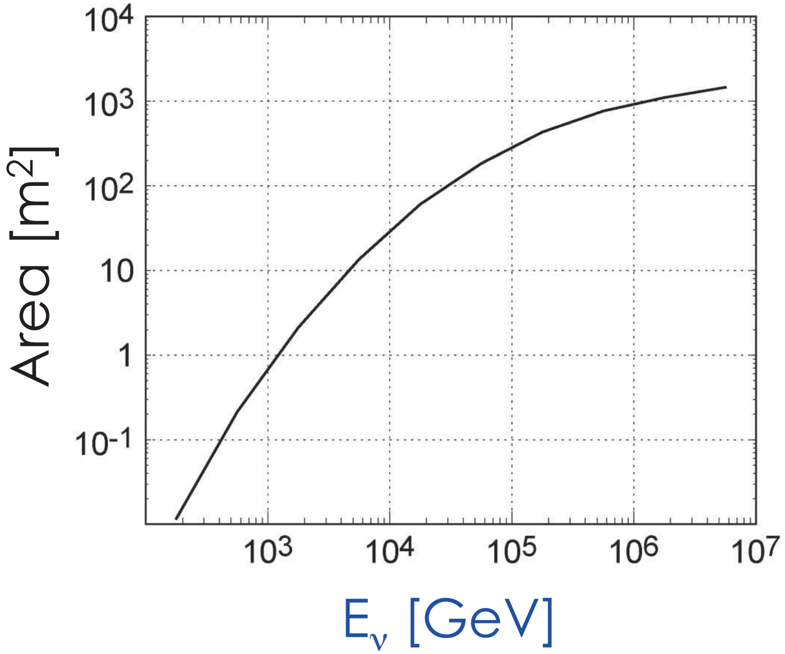


3σ @ 50%

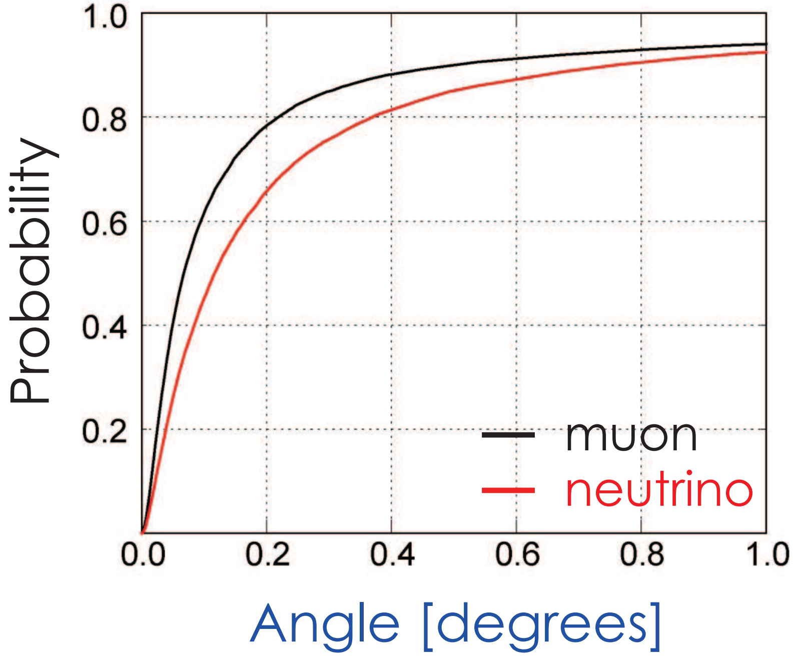
5σ @ 50%

KM3NeT Performance

Effective neutrino area



Angular resolution

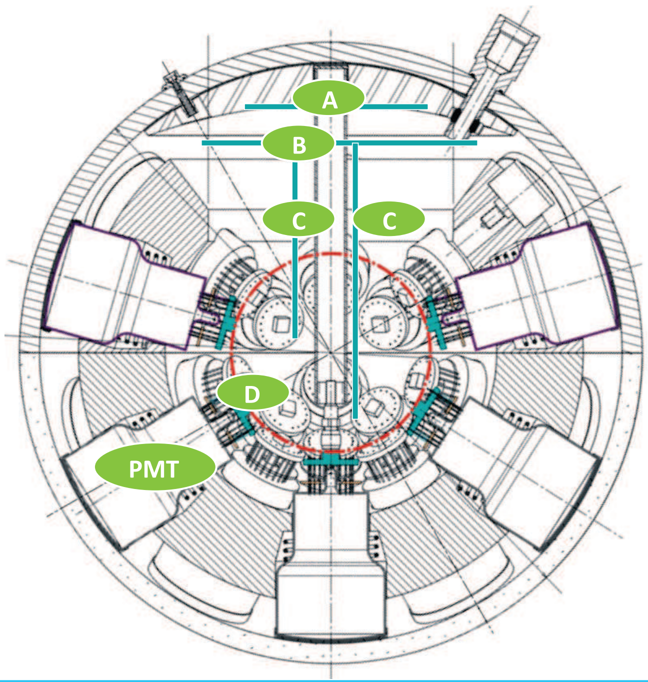


Energy resolution ~0.3 in $\log_{10}(E_\nu)$ if E_μ >1 TeV

Angle between
incoming neutrino and
reconstructed muon
dominated by kinematics
up to ~1TeV

KM3NeT technology
Multi-PMT Digital Optical Module (DOM)

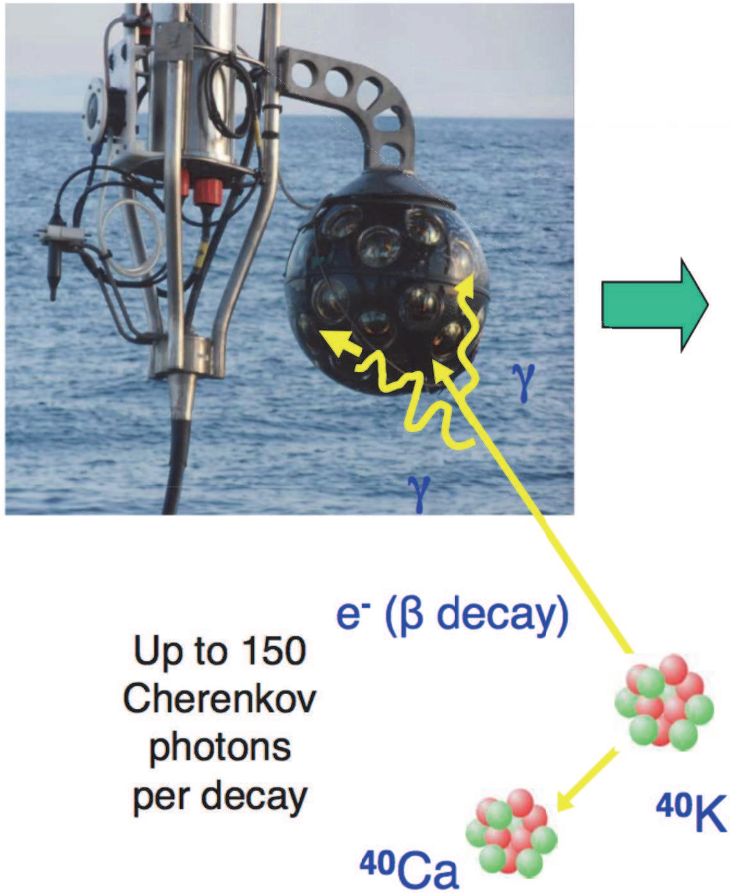
- 31 3" PMTs in 17-inch glass sphere (cathode area~ 3x10" PMTs)
  - 19 in lower, 12 in upper hemisphere
  - Light collection rings (20-40% gain)
- 31 PMT bases (total ~140 mW) **(D)**
- Front-end electronics **(B,C)**
  - FPGA readout
  - Sub-ns time stamping
  - Gb/s speed
- Al cooling shield and stem **(A)**
- Single penetrator
- Calibration:
  - LED and piezo inside sphere
- Advantage:
  - large segmented photocathode area
  - 1-vs-2 photo-electron separation: sensitivity to coincidences
  - directionality

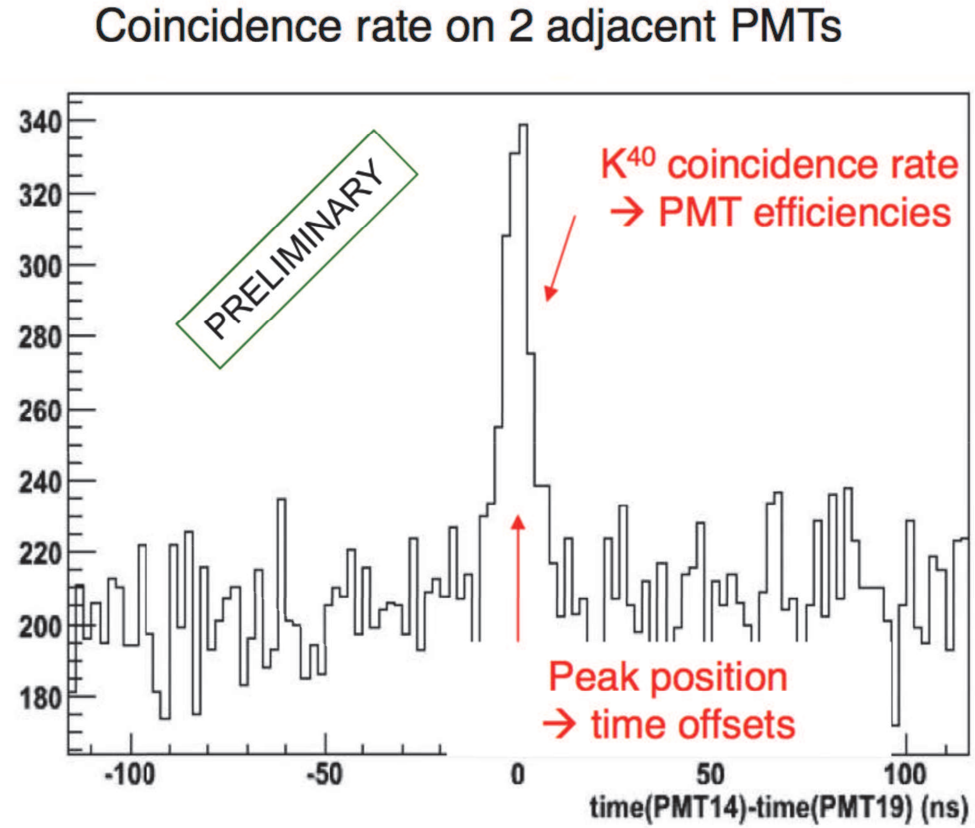


Operational DOM prototype

- Fully equipped DOM (31 PMTs + acoustic positioning sensors + time calibration LED beacon)
- Mounted on the ANTARES instrumentation line.
- Instrumentation line installed and connected on 16 April 2013
- fully operational and working correctly

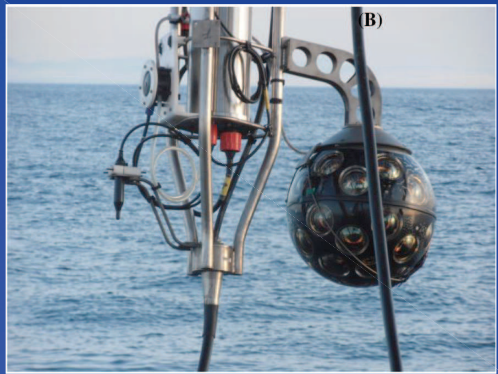
Coincidences between neighbouring PMTs



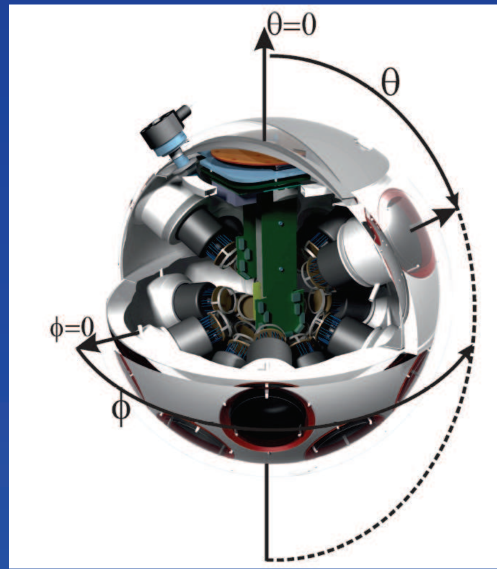


Concentration of ^{40}K is stable
(coincidence rate ~5 Hz on adjacent PMTs)

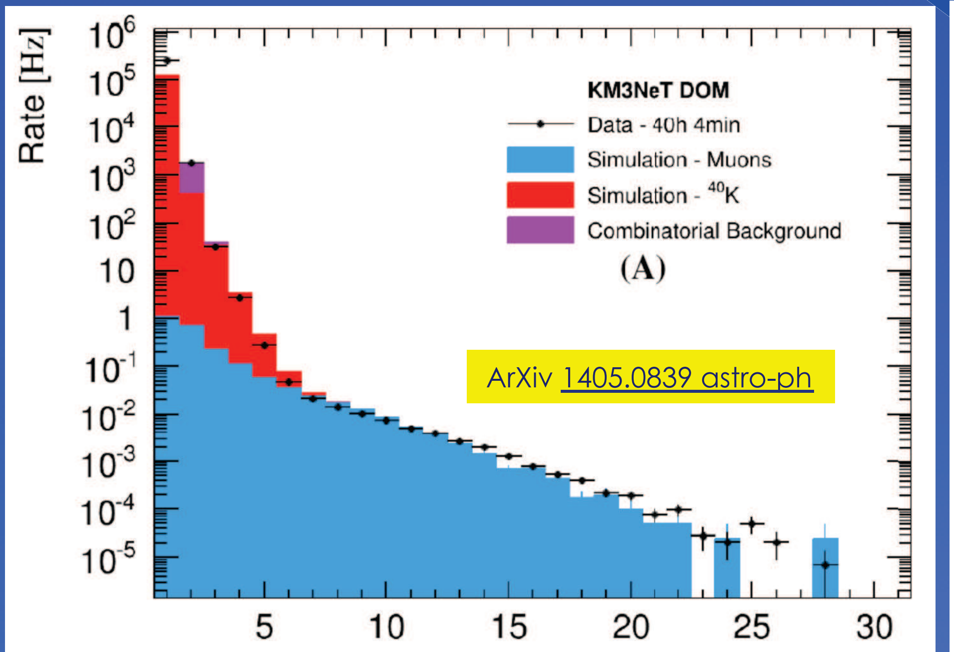
KM3NeT prototype D.O.M. in ANTARES since April 2013

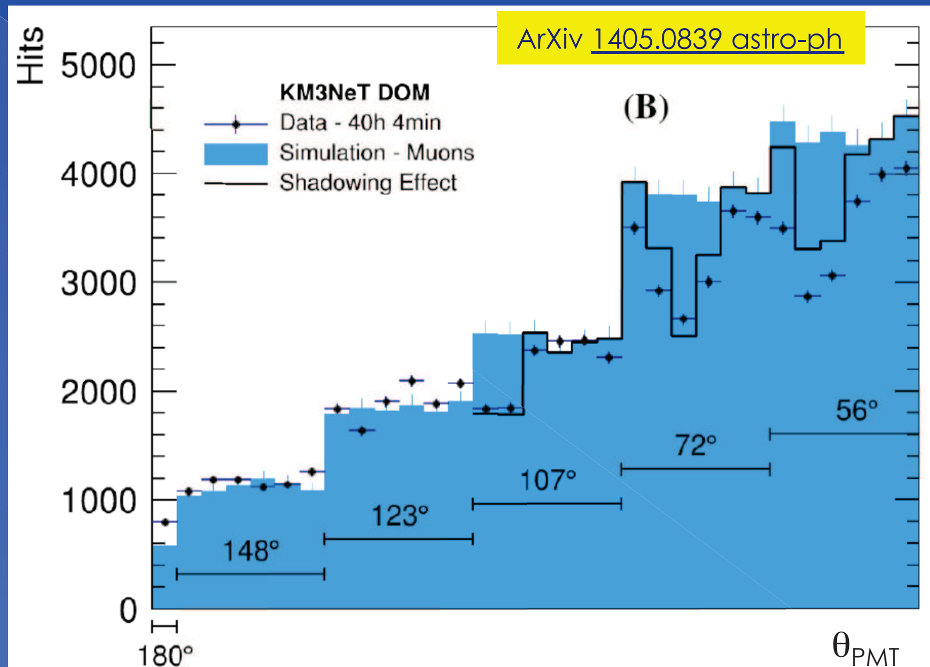


ArXiv 1405.0839 astro-ph
To be published soon



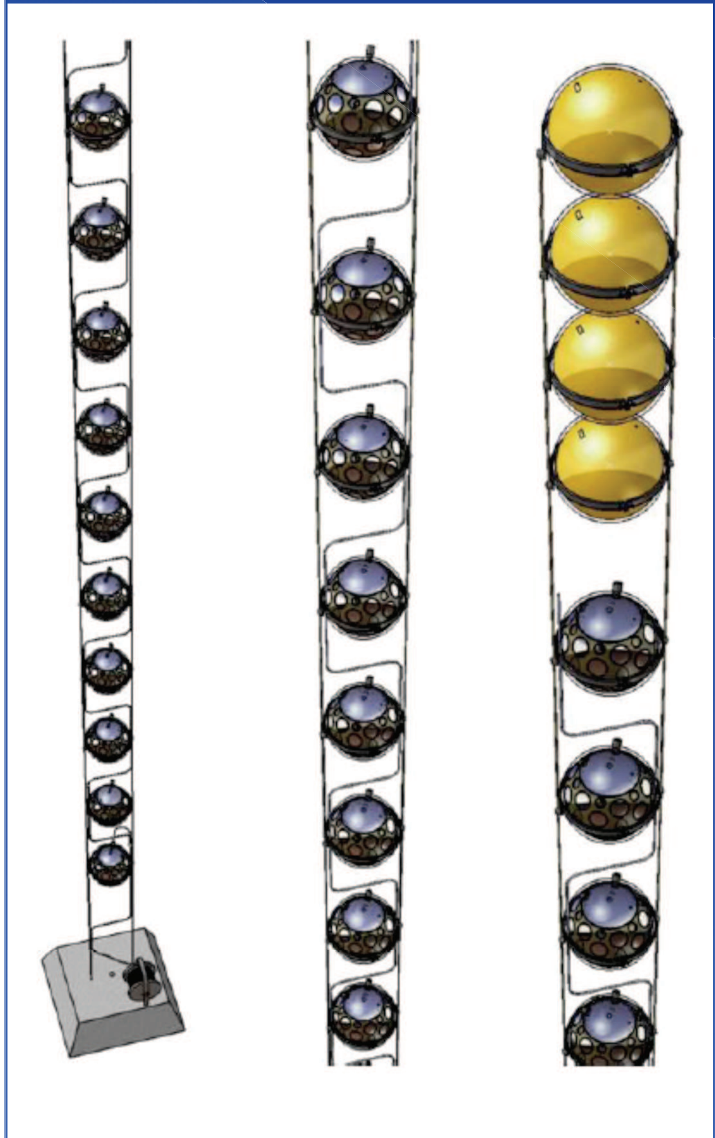
Coincidences in the DOM:
⇓
hits in different PMTs in a time window of 20ns





KM3NeT Detection Unit

String-like vertical structure with 18 KM3NeT-DOMs



Mooring line:

- Buoys for string tensioning
- 2 Dyneema© ropes
- 18 storeys (one OM each),
  36m distance, first DOM 100 m above the Seabed
- DOMs connected via electro-optical cable:
  1 fibre+2 copper wires
- Break out box with fuses at each storey
- DWDM with 80 wavelengths
  - GB/s readout
  - all data to shore

Deployment strategy

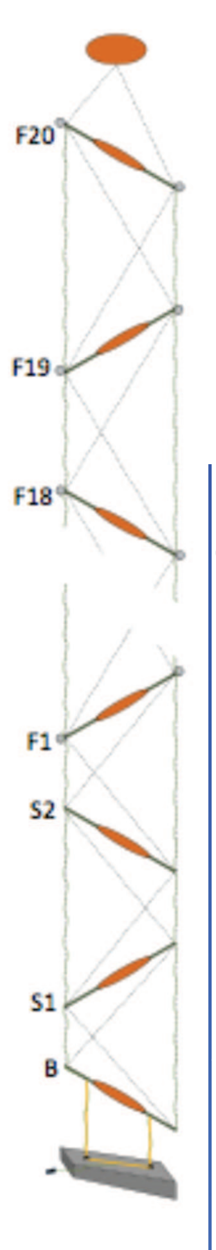
- Compact package self-unfurling
  - Eases logistics (in particular in case of several assembly lines)
  - Speeds up and eases deployment; several units can be deployed in one operation
  - Self-unfurling concepts is being thoroughly tested and verified
- Connection to seabed network by ROV

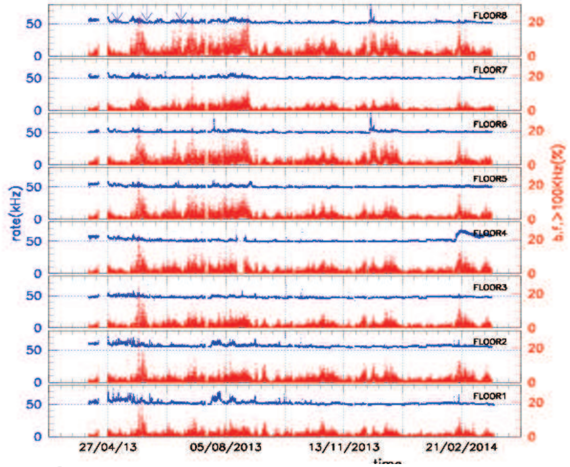
"String compactification"

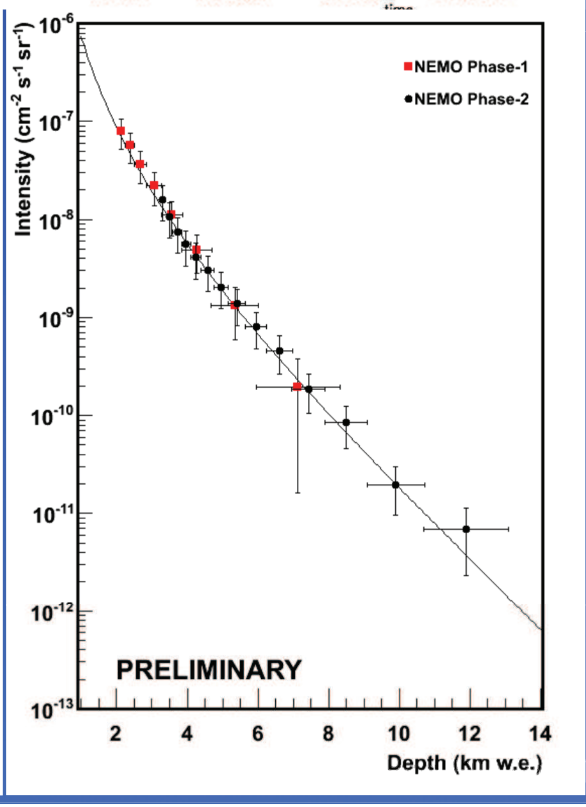
- First successful test in December 2009

Detectors operational at KM3NeT-It site, May 2014

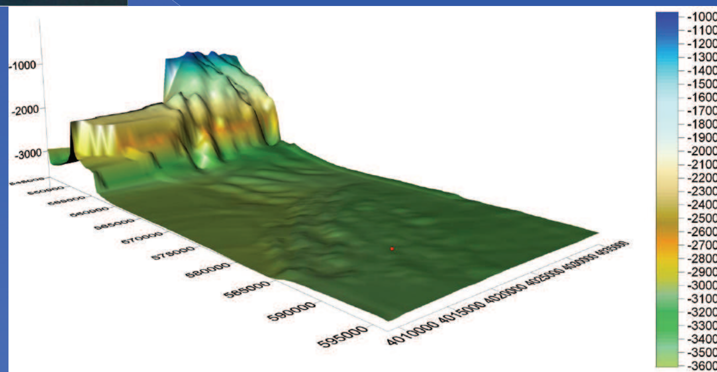
Since March 2013 the NEMO-Phase2 Tower







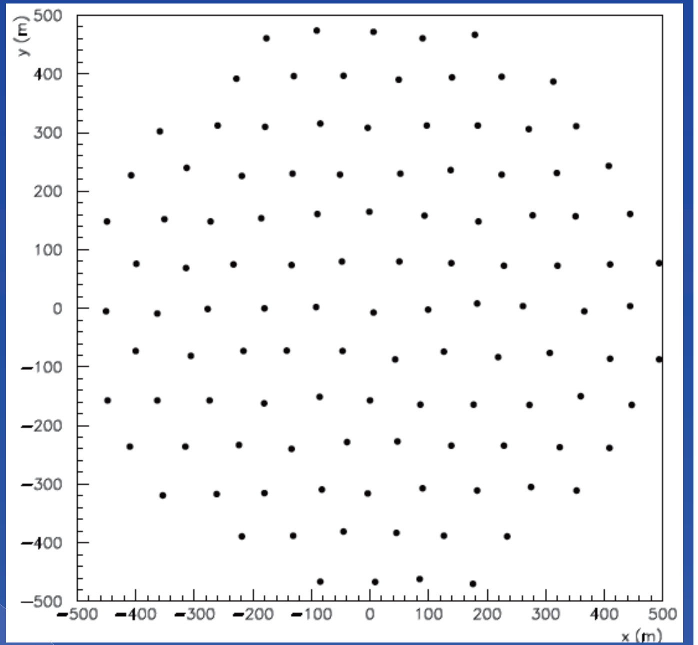
Since May 8th 2014:
Prototype KM3NeT detection unit with 3 DOMs



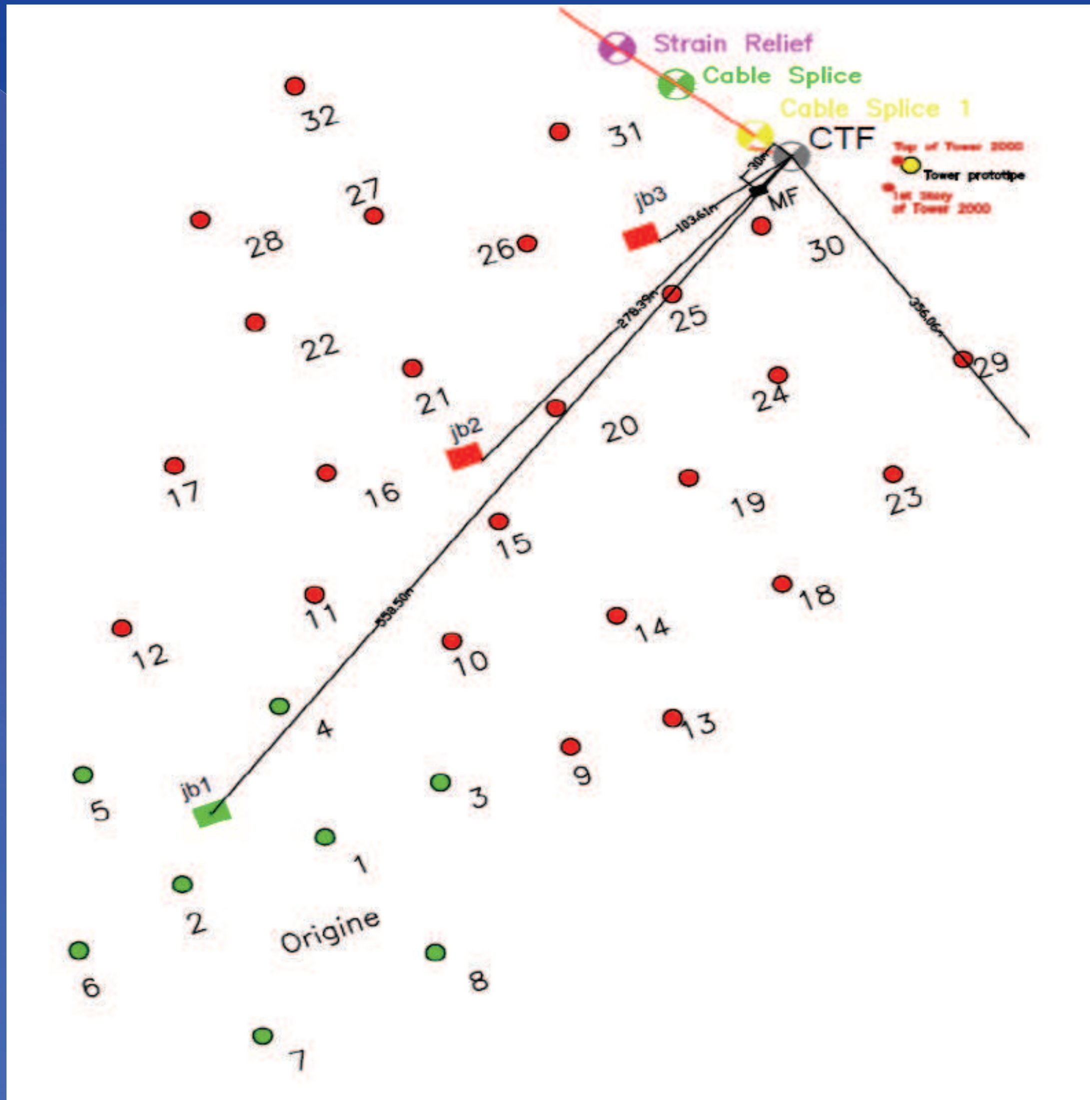
The building block concept

Simulated configuration:
115 DUs, 90m distance on average

- Building block:
  - 115 detection units
  - Segmentation enforced by technical reasons
  - Sensitivity for muons independent of block size above ~75 strings
  - One block ~ half IceCube
- Geometry parameters optimised for galactic sources (1 < E_ν <100 TeV, and cut-off)
- Technical feasibility verified
- **KM3NeT includes 6 building blocks**



First phase of seabed layout at the KM3NeT-It



KM3NeT status

- Collaboration since 29 January 2013
  - MoU
  - 38 institutes, 241 members

- Resources Review Board (RRB) in place

- Scientific and Technical Advisory Committee (STAC) in place

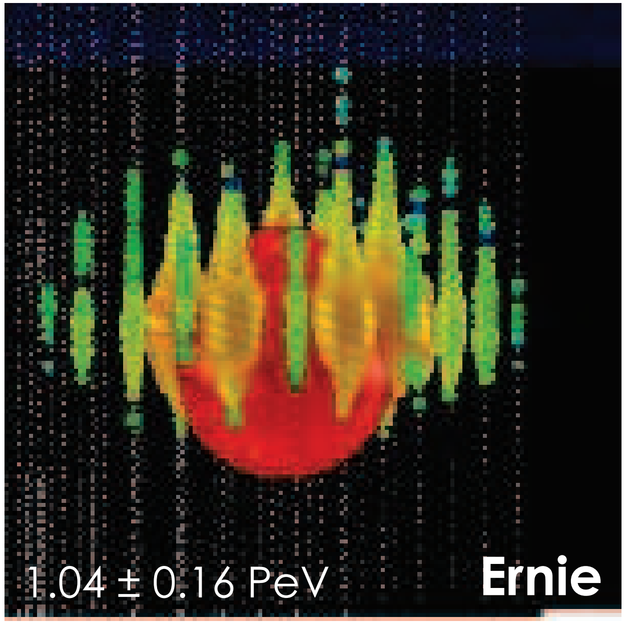
- Funding available for implementation of first phase of KM3NeT Research Infrastructure:
  - Two installation sites being prepared: KM3NeT-Fr and KM3NeT-It
  - KM3Net-IT site: 24 Strings + 8 Towers (like NEMO tower)
  - KM3Net-Fr site: 6 Strings
  - 2 nodes for connection for marine science instruments

Summary

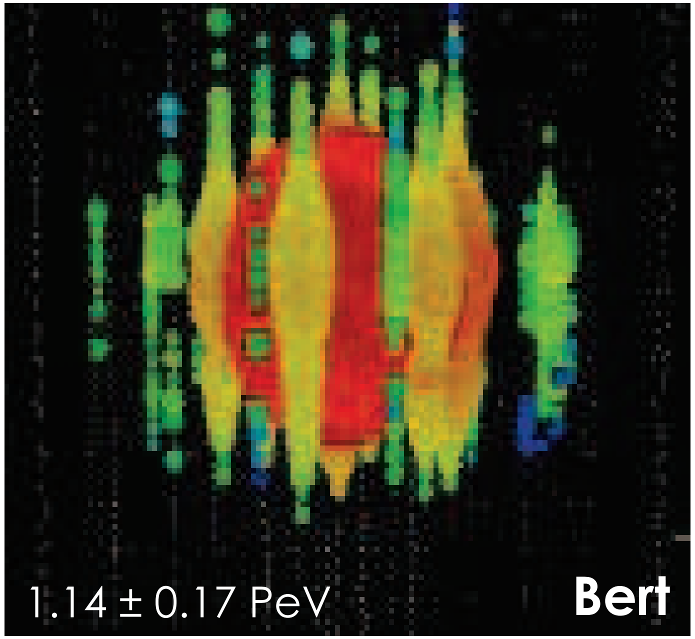
- Neutrino astronomy has made in the last year tremendous progresses
  - IceCube evidence for H.E. cosmic neutrinos: their origin is still unknown
- ANTARES, the larger Cherenkov Neutrino detector in the Northern Hemisphere
  - demonstrated the feasibility of a deep-Sea Neutrino Telescope
  - has competitive results w/r to IceCube
  - has started/exploited several multimessenger searches
- International KM3NeT Collaboration is working for a staged multi-sites construction of the several-km^3 Cherenkov ν Telescope
- First implementation of the KM3NeT telescope started:
  - Seabed network and shore station KM3NeT-Fr and KM3NeT-It
  - Connection of 6 KM3NeT detection units at KM3NeT-Fr
  - Connections of 24 KM3NeT detection units plus ~8 Towers at KM3NeT-It.
- Aiming at a volume of ~5 times IceCube for the full KM3NeT detector

IceCube Discovery !!!!

The first two VHE astrophysical ν events observed by IceCUBE



312 DOMs

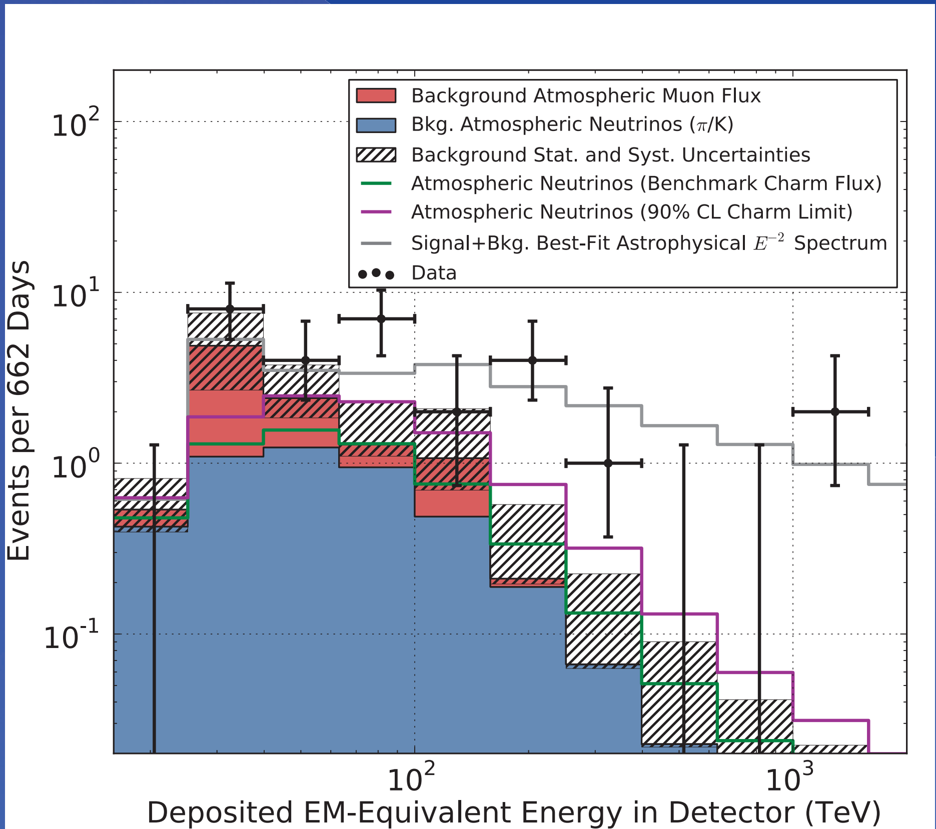


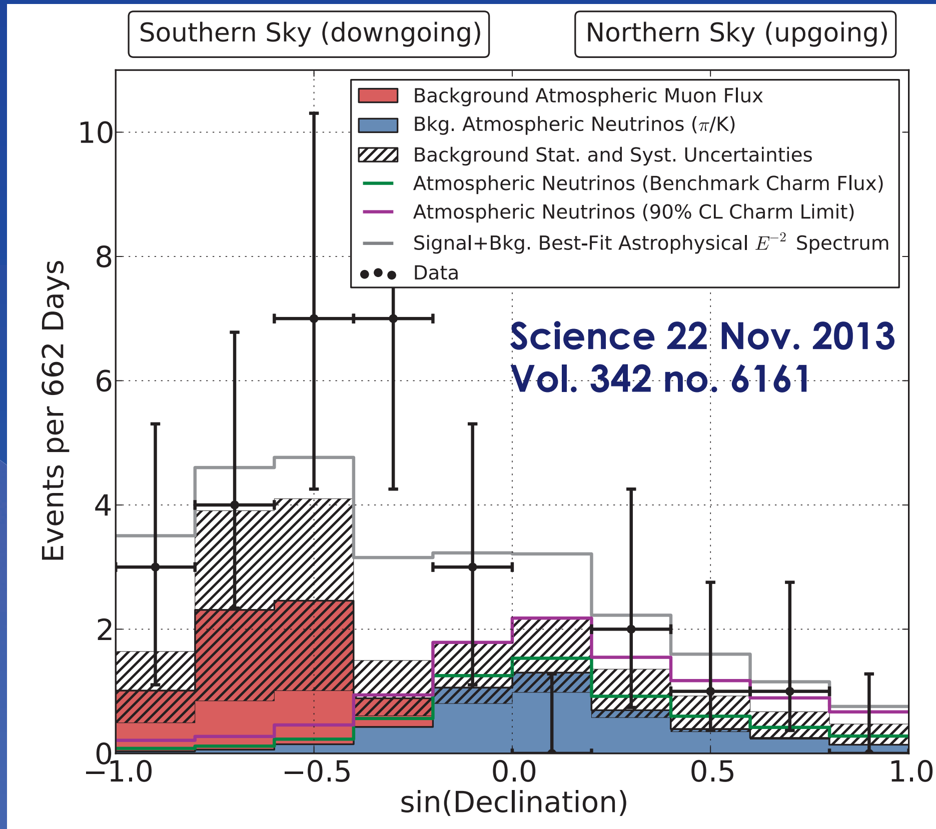
354 DOMs

Two neutrino events of energy above 10^{15} eV detected in IceCube were reported on Neutrino 2012 Conference.
T. Stanev @ Now 2012 Conference: "The first thought was that these events are produced by electron antineutrinos generating the Glashow resonance."

IceCube Discovery !!!!

28 contained VHE astrophysical ν events reported by IceCUBE



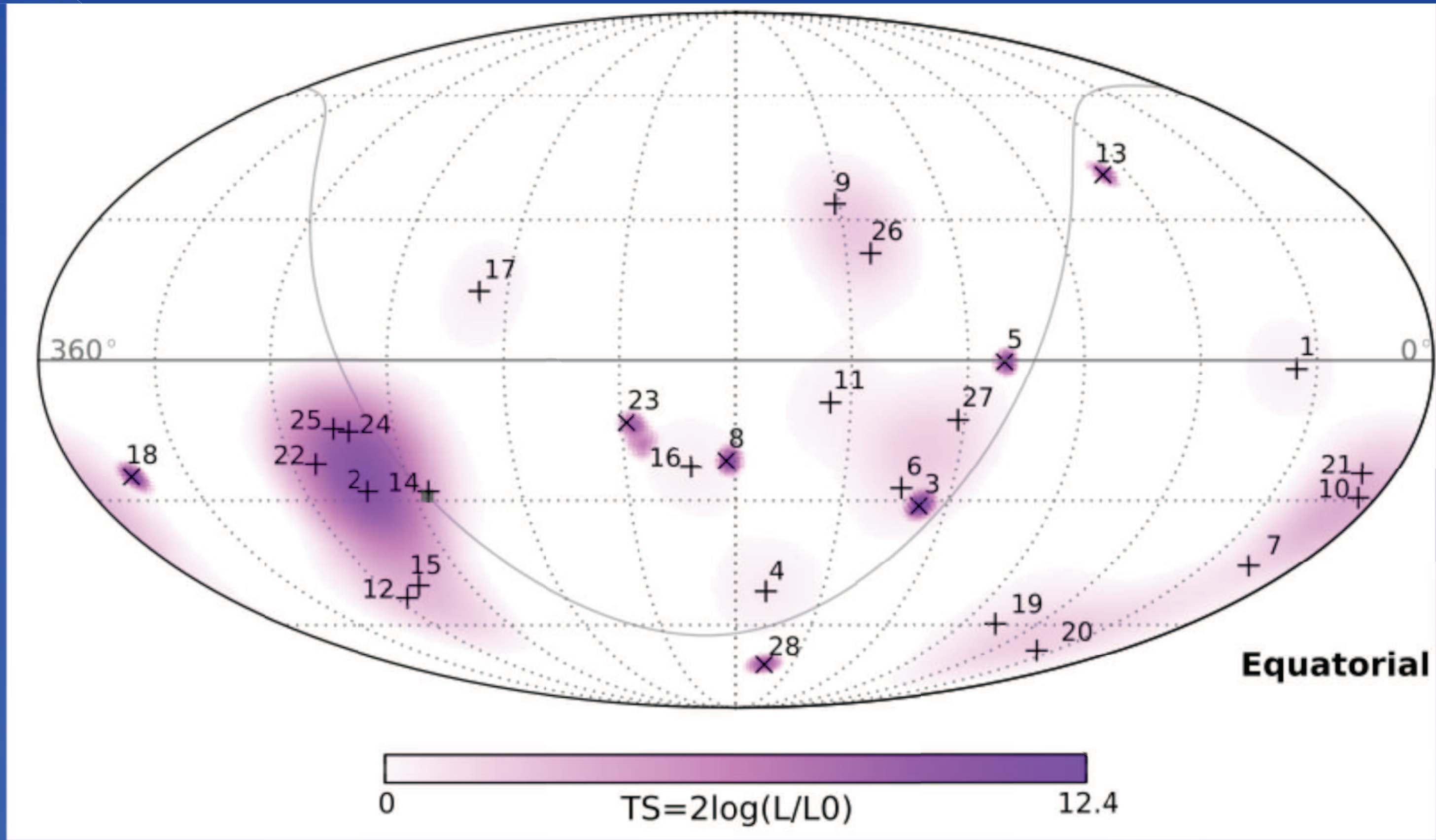


- Observed energy distribution harder that any expected atmospheric background
- Measured event sample compatible with isotropic neutrino flux

THE NEUTRINO ASTRONOMY CHAPTER IS NOW OPEN !!!

IceCube Discovery !!!!

28 contained VHE astrophysical ν events reported by IceCUBE



Skymap in equatorial coordinates of the Test Statistic value (TS) from the maximum likelihood point-source analysis. The most significant cluster consists of five events (all showers and including the second-highest energy event in the sample) with a final significance of 8%. Best-fit locations of individual events are indicated with vertical crosses (+) for showers and angled crosses (x) for muon tracks.

KM3NeT: a distributed Research Infrastructure

- Centrally managed
- Common hardware
- Common software, data handling and operation control
- Sites in France, Greece, Italy
- Consistent with funding structure (regional sources)